

# FINAL REPORT

Rapid Deployment of Optimal Control for Building HVAC  
Systems using Innovative Software Tools and a Hybrid  
Heuristic/Model-Based Control Approach

ESTCP Project EW-201409

MARCH 2017

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## ACRONYMS AND ABBREVIATIONS

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AC	Air Conditioning
AHU	Air Handling Unit: an HVAC system component that contains a fan and heating/cooling equipment
ALC	Automated Logic Controls Corporation (a division of United Technologies): a controls equipment manufacturer
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
BAS	Building Automation System
BLOM	Berkeley Library for Optimization Modeling: a general-purpose optimization modeling language
BOMP	BrightBox Optimization Modeling Platform: an HVAC control system modeling platform developed by BrightBox Technologies
C++	C plus plus: a modern, object-oriented computer programming language
CAV	Constant Air Volume
DDC	Direct Digital Controls: short-hand for computerized, networked building controls
DoD	Department of Defense
ESTCP	Environmental Security Technology Certification Program
FOH	First Order Hold: a category describing time-varying data used in solving control problems
HVAC	Heating, Ventilating, and Air-Conditioning
IBM	International Business Machines; a large computer hardware and software company
IPMVP	International Performance Monitoring and Verification Protocol
LCDR	Lieutenant Commander
ME	Mechanical Engineering
MPC	Model Predictive Control: a model-based system control approach
M&V	Monitoring and Verification
NPS	Naval Postgraduate School Monterey
NSAM	Naval Support Activity Monterey
NSA	Naval Support Activity
PE	Professional Engineer
PG&E	Pacific Gas & Electric: a California utility company
PI	Proportional + Integral: a common software element for system control

PID	Proportional + Integral + Derivative: a common software element for system control
PWA	Piecewise Affine
TOPP	Theoretical Optimum Plant Power
UC	University of California
UCB	University of California, Berkeley
VAV	Variable-Air Volume; also refers to a “VAV box,” which is a simple HVAC system component
VAVR	Variable-Air Volume Reheat; a type of VAV box that also contains a heating coil
VFD	Variable Frequency Drive
VP	Vice President
ZOH	Zero Order Hold: a category describing time-varying data used in solving control problems

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## EXECUTIVE SUMMARY

ESTCP project EW-201409 aimed at demonstrating the benefits of innovative software technology for building HVAC systems. These benefits included reduced system energy use and cost, as well as improved performance driven by autonomous commissioning and optimized system control. In the end, while many individual elements of the project were completed successfully, the project as a whole was not able to successfully demonstrate the technology.

Two buildings at the Naval Support Activity Monterey (NSAM) facility were selected for this demonstration because they met the following criteria.

- Employed an Automated Logic Controls (ALC) building control system
- Contained HVAC central plants containing multiple chillers with the correct type of control points available and integrated into the ALC system
- Employed ‘variable air volume reheat’ (VAV-reheat) HVAC distribution systems
- Contained existing energy and flow meters to enable monitoring and verification

The first building selected was Building 245 (Watkins Hall). In the end we were not able to deploy the advanced control solution to this building because of chiller equipment failure. The Watkins plant consisted of three chillers, CH-1, CH-2, and CH-3. Despite being co-located, CH-1 served Building 246 next door, which contains critical security program spaces. During this project CH-1 became permanently disabled and CH-2 was repurposed to serve Building 246. This left only CH-3 to serve the subject Building 245, making the deployment infeasible.

The second building selected was Building 305 (Glasgow Hall). At this building we were not able to deploy the advanced control software because the chilled-water supply temperature setpoint control point was not properly configured at any of the three chillers serving this building. This control point is a key element in deploying the optimal control solution and it was not available.

To resolve the issue at Glasgow Hall, we formed a team consisting of BrightBox engineers, NSAM operations staff, two different NSAM support contractors, and equipment manufacturers to identify the source of the problem and develop a solution. After months of work, the team was able to identify the hidden cause of the problem as the undocumented replacement of a control board inside the chillers that was malfunctioning. It turns out this problem dates to the original system installation and was unknown to building operators over the past 10 years. We identified a solution and the ESTCP program made funds available to implement the repair.

In the end, project timing did not allow for this solution to be implemented because at roughly the same point in time BrightBox Technologies completely ceased operations in this market due to slow adoption of our software. The situation with the Glasgow chillers highlights the need for thorough documentation of system design intent coupled with commissioning activities to verify that systems are installed, configured, and operating properly.

Anecdotal evidence, academic studies, and system simulations clearly demonstrate the importance and capacity for best-in-class control solutions to improve system performance and reduce energy use and cost. However, implementing these solutions into the extremely heterogeneous and often malfunctioning or misconfigured HVAC systems in real operating buildings poses a major challenge to reaping the benefits promised by advanced control. For these reasons, BrightBox Technologies refocused our efforts away from optimal control toward autonomous commissioning with the goal of establishing a correctly-configured and properly-operating foundation onto which optimal control could eventually be deployed. Unfortunately, we were not yet able to successfully develop a market for autonomous commissioning products despite the clear need and benefits. BrightBox Technologies ceased operations in this market at the end of March 2016.

## **1.0 INTRODUCTION**

The Department of Defense (DoD) spends approximately \$4 billion per year on facility energy consumption to power and fuel over 500 military installations worldwide. These installations include over 500,000 buildings and structures. HVAC system energy use across this portfolio represents roughly 40 percent of these costs, which equates to \$1.6 billion annually.

Despite the large number of DoD buildings, each is unique. No two buildings contain the same type or configuration of HVAC components and equipment. Contractors install custom HVAC controls in each facility to turn the individual components into functioning systems, and the quality of these control installations directly affects the efficiency and performance of the buildings they serve. Deploying highly optimized custom controls across a wide range of HVAC system types and uses is a challenging but important goal if DoD is to reduce energy costs.

BrightBox Technologies developed an innovative software solution to accomplish this goal while at the same time aiming to keep implementation costs low. The BrightBox controls optimization product worked with existing control systems in existing buildings to reduce HVAC energy use and operating costs between 20 to 40 percent. If successfully applied across the entire portfolio of DoD buildings with an average HVAC system performance increase of 25%, this would represent \$400 million in annual savings for DoD.

### **1.1 BACKGROUND**

Buildings waste energy today in part because their HVAC system controls are not optimized for energy efficiency. BrightBox Technologies developed an innovative approach to writing and deploying building control software that delivers optimized systems quickly and cost-effectively. The technology aimed to deliver 20% to 40% HVAC energy cost savings in existing buildings along with performance improvements and other benefits. This ESTCP demonstration project represented an excellent opportunity for BrightBox to extend product testing and development and demonstrate to The Department of Defense (DoD) a powerful approach that could potentially be implemented across a large portion of their existing facilities to reduce energy use, reduce utility costs, and improve energy security.

#### **1.1.1 Current Technology State of the Art**

Current product offerings from the major controls manufacturers – Johnson, Honeywell, Siemens, Automated Logic – define what is state-of-the-art in the building HVAC system controls industry. Because this industry has been hardware-focused for most of its history, those defining product offerings have also been hardware-centric, and in fact the current generation of HVAC controls hardware products are quite capable in keeping with the general advancement of the computer and IT industries. But while the hardware-side of HVAC controls has moved forward significantly, the software side has not kept up. It is only in the past 5-years or so that some of the major manufacturers have started to offer new software / user interface products, but in general across the industry the software tools and user interface do not reflect the significant advancements made in the wider software-industry.

The state of the art today with respect to commissioning is that despite a number of industry efforts to standardize the commissioning process and deliverables, it is still largely a manual ad-hoc process that varies considerably on a project-to-project and provider-to-provider basis. The benefits of commissioning are well recognized, but thorough and truly-effective commissioning is not yet applied to all projects to capture those benefits. Barriers to more widespread deployment of commissioning include high initial costs and perceived uncertainty about financial payback.

### **1.1.2 Current State of Technology in DoD**

DoD buildings employ a wide variety of HVAC control products and systems based largely on the date of the building construction and/or most recent significant retrofit. There is no standard control approach or product across all of DoD, nor is there a policy or funding available to continually upgrade building controls to the latest version. The result is a heterogeneous mix of control products and generations across DoD facilities. A few ESTCP projects have been controls-focused and some have even explored the use of predictive-analytics to affect building operation. None to date has yet had a significant impact on the large DoD building portfolio. It is also the case that many older and/or smaller DoD buildings operate without a building operating system at all, or they use standalone or pneumatic controls do not offer as much potential for performance improvement.

### **1.1.3 Technology Opportunity**

The goal of this project was to install the BrightBox software in DoD buildings to help advance the DoD mission by allowing resources currently allocated to building utility costs to be used elsewhere, specifically to spend less money on energy and on configuring BAS systems in existing buildings. This would allow for more buildings to become automated with the savings, or to allow the dollars that would have been spent on energy to be allocated elsewhere (like capital improvements, equipment replacement, or additional O&M staff).

The goal of the BrightBox software was that it would be able to work with multiple software manufacturers and software generations. At the time of this demonstration project, the BrightBox software only worked with Automated Logic Controls (ALC), but it was a future goal (outside of the scope of work for this project) to broaden the application to work with multiple control manufacturers. Through extensive data collection, it could also help unify the understanding and management of the DoD building energy performance portfolio.

The goal for the BrightBox AutoCx product was to deliver the benefits of commissioning at a much lower first cost than was previously possible. BrightBox AutoCx uses automation to reduce the amount of expensive field labor required to deploy commissioning. Following this approach, AutoCx addresses the key barriers to more widespread use of commissioning. The opportunity here was that commissioning could be deployed less expensively and more widely across DoD buildings.

## **1.2 DRIVERS**

### **1.2.1 Executive Order 13693 (EO 13693)**

Executive Order 13693 revoked Executive Order 13423 (EO 13423) from 2009, “Strengthening Federal Environmental, Energy, and Transportation Management” required federal agencies to lead by example in advancing the nation’s energy security and environmental performance in a wide variety of areas including building performance.

This executive order (13693) revoked EO 13423 on March 19, 2015, so 13423 is no longer a direct, forcing driver for this project. However, its existence does form some of the context for the ESTCP program.

EO 13693 also revoked Executive Order 13514 (EO 13514) from 2009, “Federal Leadership in Environmental, Energy, and Economic Performance,” which built on EO 13423 by adding specific target language. In the area of building performance, the goal was to “Ensure that all new construction and major renovations meet the Guiding Principles for High-Performance Sustainable Buildings, and that 15 percent of existing buildings meet them by FY 2015. Starting in FY 2020, the goal was to design federal buildings to achieve “zero net energy” by FY 2030.” The Guiding Principles for High-Performance Sustainable Buildings specifically referred to improving energy efficiency.

Like EO 13423 discussed above, EO 13514 was revoked on March 19, 2015, so it is no longer a direct, forcing driver for this project. However, its existence does form some of the context for the ESTCP program.

### **1.2.2 Federal Energy Independence and Security Act (Public Law 110-140)**

The Energy Independence and Security Act (Public Law 110-140) from 2007 specifically aims to increase the efficiency of buildings among other things. This project will contribute to that goal.

### **1.2.3 Department of Defense Strategic Sustainability Performance Plan (SSPP)**

The Department of Defense Strategic Sustainability Performance Plan (SSPP) from 2012, and updated in 2014, established the path by which DoD will improve practices that further the sustainability goals of the nation. In particular the DoD intends to integrate sustainability into the everyday course of DoD business. The plan requires an annual target reduction 3% in facility energy intensity across the DoD. This project will contribute to that goal.

### **1.2.4 Navy Service Policy UFC 1-200-02**

Navy Service Policy UFC 1-200-02, last updated in August 2014 “High Performance and Sustainable Building Requirements” was specifically created to “drive transformation in the performance of the DOD facility inventory.” Areas of performance include: 1) energy efficiency, 2) optimized energy performance, and 3) measurement and verification. This project makes contributions in all three of these performance areas.

### **1.3 OBJECTIVE OF THE DEMONSTRATION**

Our objective was to demonstrate how BrightBox software could be used to quickly and cost-effectively develop and deploy optimized controls across a wide array of existing buildings. Our approach was to deploy the BrightBox software at the Naval Support Activity Monterey (NSAM) in Monterey, California. This DoD site represents approximately 1.2 million square feet of space and contains more than 25 separate buildings. No two buildings at NSAM contain identical HVAC systems, and the systems were installed anywhere from 1930 to the present. The systems at NSAM represent a wide range from the simple (baseboard heaters coupled with operable windows) to the complex (multiple-chiller plant serving data centers operating 24x7, large central steam boiler plant). With the help of NSAM staff, we identified a subset of NSAM buildings to receive the BrightBox software that represent an interesting and relevant sample of the buildings on campus. The project objective was for software to be installed in these buildings and the impacts assessed to quantitatively and qualitatively judge the effectiveness of the installation.

#### **1.3.1 Validate**

The objective was for baseline performance data to be collected to form the basis for the validation. Validation was to occur via independent measurements of system performance after the BrightBox implementation and then compare new performance to the baseline.

The objective for AutoCx validation was to assess the current operational state of individual equipment components in the project sites to form the basis for the validation. AutoCx software would then be used to test equipment operation, and any deficiencies will be noted and referred to NSAM operations staff.

#### **1.3.2 Findings and Guidelines**

If the BrightBox demonstration met performance objectives, DoD might have wanted to implement general guidelines for building analytics technology using the BrightBox Technology as an example across a wider range of buildings. Guidelines could have been developed for evaluating the potential for building system optimization and AutoCx technology to save energy and money at other DoD sites.

#### **1.3.3 Technology Transfer**

A successful demonstration project would have resulted in data and supporting analysis that could have been used to launch successive projects at other DoD installations. In this case, BrightBox would have developed a case study document based on this ESTCP project that summarized goals, process, technology, and results. We understand that there are significant security-related issues to implementing BrightBox at other DoD facilities that have more rigorous security protocols than NSAM. One approach to addressing these security concerns would have been employing third-party secure hosting services such as the Amazon “secure cloud” service. It is possible that this new resource offers a valuable secure IT platform.

In addition, in the case of a successful demonstration, BrightBox would have developed recommended additions to the DoD whole building design guide Unified Facilities Criteria specifically in sections UFC 3-401-01 Mechanical Engineering and UFC 3-410-01 Heating, Ventilating, and Air Conditioning Systems. Finally, BrightBox would have produce a fact sheet for channel partners who have DoD accounts with specific information on how to implement the BrightBox technology in a DoD environment.

#### **1.3.4 Acceptance**

The objective for this project was that documented energy and demand savings at the NSAM site would have driven acceptance of the BrightBox approach for implementation at additional DoD facilities.

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## **2.0 TECHNOLOGY DESCRIPTION**

BrightBox Technologies created software with the goal to make it possible to quickly and cost-effectively develop and deploy optimized controls software into existing buildings. We developed an innovative analytical framework in which complex building controls problems can be quickly described, solved, and optimized. The framework also allowed us to apply, test, and verify the resulting controls solutions. Further, it enabled new functionality (planned for future development) such as effective demand response and predictive information exchange with smart utility grids.

One reason that it has historically been difficult to achieve energy savings across large groups of existing buildings is that each building is unique. Equipment, components, systems, and configurations vary sometimes substantially from project to project based on the competitive nature of the market and the wide proliferation of available products as well as the one-off nature of the building design and construction process. The result is that energy efficiency measures that make sense in one building very likely may not in another. To correctly assess energy efficiency measures, each building needs to be considered independently.

BrightBox Technologies understood this need to create custom solutions for every project, and built a suite of software applications to attempt to effectively address this challenge. Our software allowed for buildings and systems to be quickly and correctly defined in a robust analytical modeling platform. Once these models were built, they were fed with current and historical data streams from the existing Building Management System (BMS), which were then used to calibrate the models for individual buildings based on real-world performance. These calibrated models then set the context in which optimization algorithms run and auto-generate new controls code. Finally, these optimized programs were executed and the resulting control parameters were delivered in real-time for use by existing building control components and embedded software.

Another barrier to energy efficiency that relates to the uniqueness of buildings is that it is difficult for operations staff to understand if each individual building control system is set up correctly and all equipment components are operating correctly at all times across the wide variety of deployed systems. Over the life of a building, equipment performance changes and components break, and it is possible that these changes can go unnoticed by operators. It is typically an indirect process by which problems are reported (often by occupants as ‘complaints’). The BrightBox system includes an ‘AutoCx’ product that systematically checks for correct system configuration and component operation, which directly, rather than indirectly, validates system setup and operation. Directly assessing and addressing setup and operation issues becomes the first phase of optimization, which reduces time to successful deployment and operation of model-based optimization.

DoD facility HVAC systems represent a wide range of applications from the simple to the complex. BrightBox development through 2013 has focused on HVAC systems such as ‘simpler’ system such as packaged rooftop direct-exchange (DX) cooling systems, hot-water boiler plants, and variable air volume reheat (VAVR) distribution systems.

More complex “built up” systems and chilled water plants are widely employed as the cooling source for large buildings and campuses. They often account for 20% to 30% of the total energy usage by these facilities [17]. Optimizing controls for chilled water plant systems alone can reduce their energy consumption up to 30% [15]. As stated above, the optimizations have to be performed for each individual system accounting for the project’s climate, cooling load, the characteristics of the plant equipment and system configuration. Consequently, most built-up systems and chilled water plants use standard control sequences that are not optimized for an individual application.

A few mechanical design firms have attempted to address this problem over the past decade. Alameda, California-based Taylor Engineering has been a leader in this effort, developing a set of software tools that can be used for determining the optimum control sequence for a water-cooled chiller plant. The approach uses a brute force optimization method that literally evaluates the full range of all control parameters then identifies the most efficient control scheme that will satisfy the load and equipment operating constraints. Taylor Engineering has validated the simulations using field measurements [16].

Unfortunately, these current chilled-water plant optimization tools are prohibitively slow to deploy and run because they do not employ a modular/flexible system modeling approach or modern optimization techniques to find the solution. BrightBox Technologies and Taylor Engineering collaborated on this project to incorporate the existing approach with research performed by BrightBox Technologies Chief Technology Officer Francesco Borrelli, PhD., to significantly reduce the system modeling effort and the computational time needed for this approach, and to further improve the results. Working together, BrightBox and Taylor Engineering extended the existing analytical tools to cover built-up systems.

The proven approach developed by Taylor Engineering was combined with the BrightBox software tools informed by Dr. Borrelli’s research to allow us to attempt to demonstrate to DoD a method to quickly and accurately generate and implement optimal controls for basic chilled water plants.

## **2.1 TECHNOLOGY OVERVIEW**

The primary objective of the BrightBox software solution was to quickly and correctly develop and implement optimized controls for HVAC systems in existing non-residential buildings. Our approach to accomplish this goal consisted of the following elements.

- The BrightBox Optimization Platform. This is a computer modeling language and set of associated algorithms designed specifically for describing and solving complex building controls problems.
- A software platform that created a user interface for the BrightBox Optimization Language, designed with HVAC system templates and objects for quick and accurate modeling
- A communication and data-acquisition interface to existing building control system hardware and software platforms

- A real-time operating system that gathers HVAC system performance data and executed the optimization solver at regularly-scheduled intervals.
- AutoCx that validates basic equipment connectivity and functionality, and control system setup.

### 2.1.1 Description

The core of the BrightBox technology platform was the BrightBox Optimization Modeling Platform (BOMP). We developed this platform to allow for the complete description of HVAC controls problems in a manner that can be used to directly generate custom optimization solutions for any given building. This innovation allowed us to effectively capture the extremely heterogeneous world of existing HVAC systems and deal with them in a rational, systematic, and time-efficient manner. Behind the scenes, BOMP automatically generated powerful system descriptions using the Berkeley Library for Optimization Modeling (BLOM).

Now publicly available, BLOM was developed at UC Berkeley by Dr. Borrelli's research group specifically to describe and solve complex optimization problems. It enables automated C++ code generation and explicit evaluation of the Jacobian and Hessian matrix formulations of these control problems. BLOM was developed in part with funding from a past ESTCP project (Project: EW-201142, Energy Performance Monitoring and Optimization System for DoD Campuses).

BLOM consists of two main components: 1) a general-purpose collection of block diagram components for use in the Simulink/Matlab graphical modeling environment, and 2) a set of functions that run outside of Matlab that export system models to a variety of optimization solvers.

The visual block diagram representation of a system model intuitively captures the signal flow, connectivity, and hierarchy of a large-scale system. It supported the following operational phases:

1. System modeling by using intuitive component block diagrams
2. Forward simulation and validation of the model
3. Automatic export of the optimization problem to an efficient optimization solver
4. Solver finds optimal solution
5. Operational setpoints are extracted from the optimal solution and input to building control system
6. Repeat steps 2 through 5 every 5 minutes

BLOM is a powerful tool that has been developed to solve complex optimization problems. It allows automated C++ code generation and explicit evaluation of Jacobian and Hessian matrices, which are important and difficult-to-solve components used in determining optimal control solutions. A BLOM model could also use standard forward simulation features for verification and comparison with optimization results. Thus, the same model can be initially run in forward simulation mode, in order to compare it to reference data, and later can be automatically exported to an optimization solver.

There are two classes of input signals to a BLOM model: unknown signals that the optimization algorithm is free to adjust in order to minimize the cost function subject to constraints (sometimes also called degrees of freedom), and time-varying signals with a known trajectory of values over a future horizon. We will refer to the former as control inputs, and the latter as external inputs. In a model-based control problem, external inputs correspond to predicted future model parameters or disturbances. Both classes of inputs are parameterized as uniformly sampled time series. Time variation for each input signal within one time step is important for discretization accuracy. It can be either piecewise linear and continuous (first order hold (FOH)), or piecewise constant with discontinuities at the sample times (zero order hold (ZOH)).

While the BLOM package itself is a flexible and powerful language, it has some inherent limitations that make it difficult to use outside of a research environment. First, the native interface to BLOM is the Simulink graphic design/analysis tool that operates in the Matlab analytical platform. Simulink and Matlab are specialized, proprietary, research-oriented software packages that are expensive to operate and difficult to learn. Further, the Matlab environment is not suitable for real-time operation due to memory and license management issues. Matlab was simply not designed to be used in this mode.

BrightBox Technologies made the power of BLOM available for solving HVAC system controls problems by creating our own custom interface and extensions to the language, which we call the BrightBox Optimization Modeling Platform (BOMP). This approach allowed us to eliminate Simulink/Matlab from our software tool-chain and enabled us to present to users an interface that is purpose-built for solving HVAC controls problems.

Further, BOMP enhanced and extended the BLOM functionality. In BOMP, we merged a BLOM model with a database schema connected to historical and real-time data feeds. This unique, innovative approach allowed for parameter identification and curve-fitting based on historical data. Another benefit was that real-time optimal control based on current observed measurements are generated in a seamless fashion, implemented as a single query on a BrightBox BOMP model as outlined in steps 1-6 above.

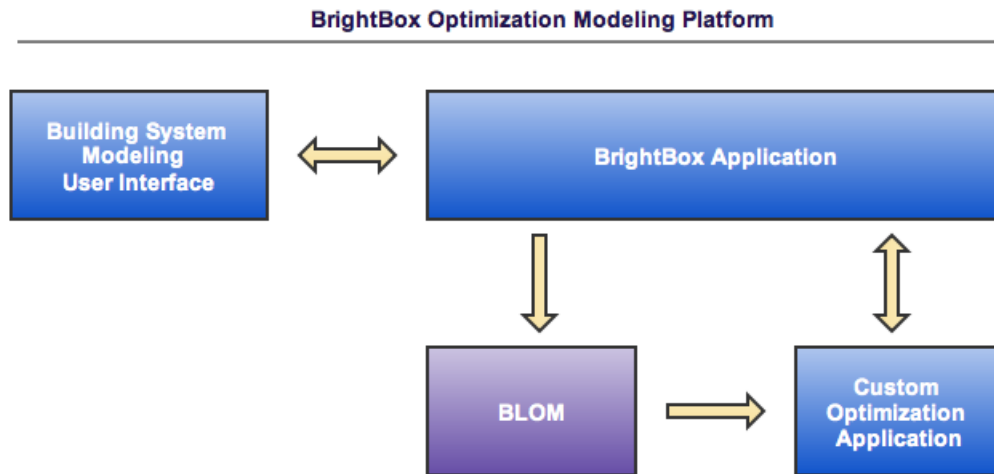
#### **2.1.1.1 AutoCX**

One result of the BrightBox market-explorations and product-development work from 2013 through early 2016 was that we clearly came to view optimization as the ‘top of the pyramid’ in that it relies on the physical components in the building to be working correctly before optimization can achieve its full benefit. If equipment is broken or misconfigured, the optimization will not succeed, or at least will not deliver its full potential.

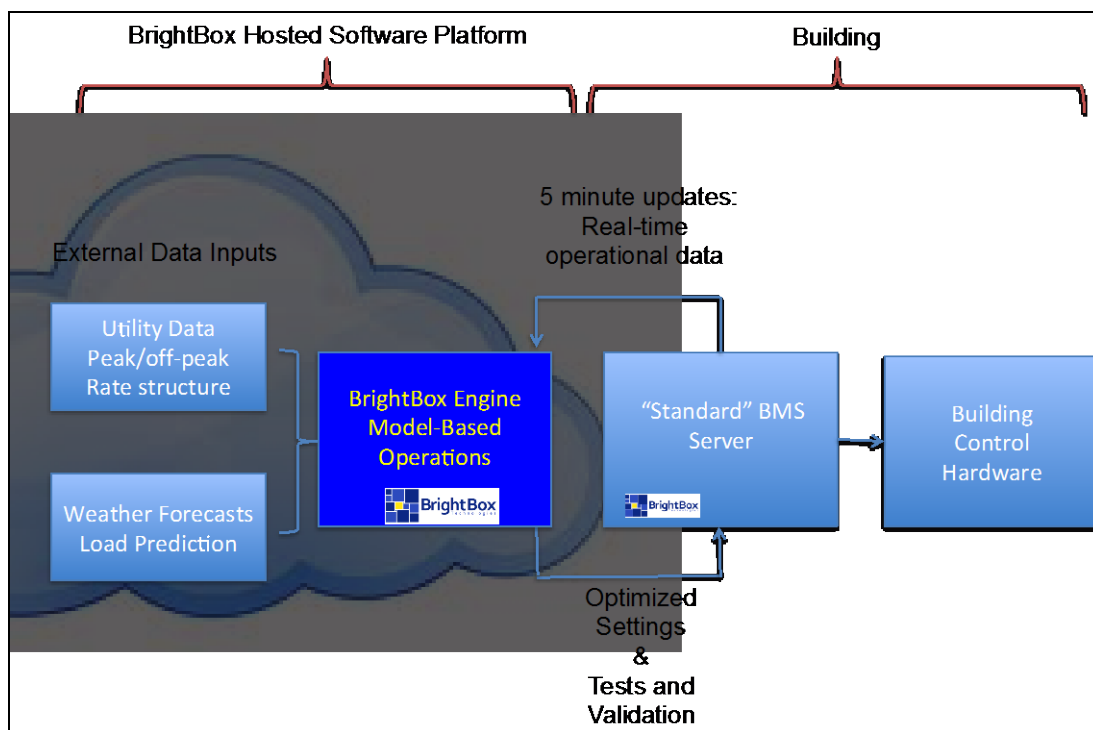
To address this issue and to help create a solid foundation for optimization, BrightBox developed an “Autonomous Commissioning” product (called AutoCx) that performs point-to-point checkout of certain types of equipment to validate correct operation and pinpoint any installation or equipment failure issues. We used our AutoCx product at the demonstration site as part of this project. We now consider it a critical phase of diagnostics that runs in parallel with the model-based optimization control we are deploying.

The goal of AutoCx was to save time in the deployment of our optimization software. We directly identify configuration and operational issues rather than indirectly discover them through a mismatch between expected and observed system operation.

### 2.1.2 Visual Depiction

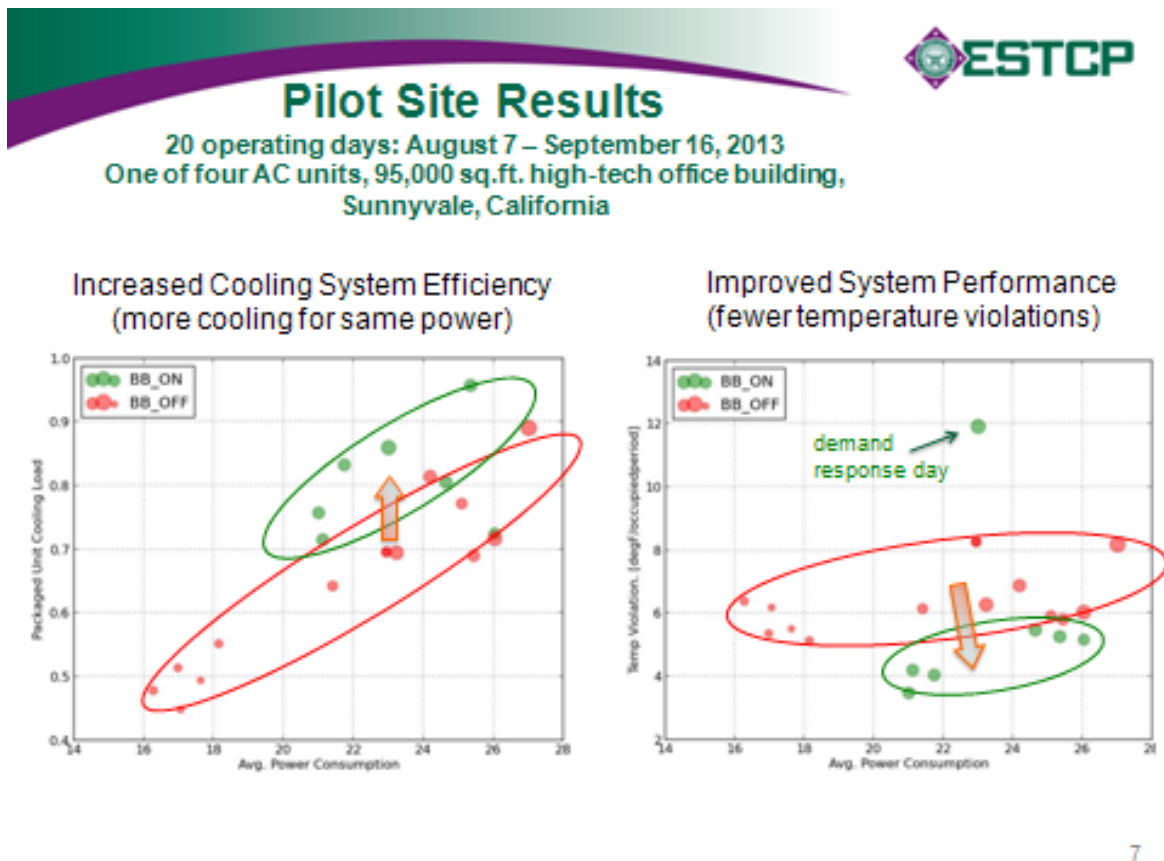


**Figure 1. BrightBox Optimization Modeling Platform**



**Figure 2. BrightBox Software Architecture and Interaction with Building**

We recognized the need for a dashboard and real-time savings reports for building managers but those are future developments outside of the scope of this project. We do have some slides demonstrating energy savings that the system generates. See Figure 3 below.



**Figure 3. BrightBox Software Energy Savings Report**

## 2.1.3 Chronological Summary

### 2.1.3.1 UC Berkeley Foundations

For the past seven years, BrightBox Technologies Chief Technology Officer Francesco Borrelli, PhD., has led the University of California, Berkeley (UCB) Mechanical Engineering research group that focuses on the theoretical and real-time implementation aspects of optimal model-based control design. He has extensive experience with linear, nonlinear, and hybrid systems in both small scale and complex large scale applications.

Dr. Borrelli and his UCB group have developed optimal control algorithms with experimental validation on a wide range of systems in the automotive field, in process industries, and in robotics, including several full-scale industrial problems [1-7].

### **2.1.3.2 Taylor Engineering Partnership**

Taylor Engineering, an active consulting mechanical engineering firm and co-performer for this project, has already successfully collaborated with the UC Berkeley controls group on a project to optimize the control sequences for the central plant at the University of California, Merced. BrightBox Technologies Vice-President of Engineering Allan Daly is also a Principal at Taylor Engineering.

As part of this project, BrightBox Technologies software was extended to incorporate existing work developed by Taylor Engineering that makes use of the following elements:

- Performance data for chillers that use manufacturer data as well as real-world performance data determined by power meters installed in the field. Similar calibration techniques will be used for pumps, heat exchangers, chillers and cooling towers (as appropriate for the specific systems under study).
- Analytical models that account for equipment specifications, chilled water load and flow profile, and the coincident weather data. This program tests all of the possible operating modes for the plant against each hour of load, flow, and weather data. For each of the modes that meet the demands (load and flow) within the operating constraints of the equipment, the program calculates the plant energy and records the results. This step for a large plant can take up to 2-3 days running on 2-5 computers depending on the number of chillers, pumps, and towers.
- A database query used to identify the minimum plant energy (or plant energy cost) at each hour, summed up to provide the Theoretical Optimum Plant Power (TOPP). We then query the database to compare the proposed control scheme against the TOPP value.

BrightBox Technologies employed a systematic approach using system identification for hybrid systems. Hybrid systems are heterogeneous dynamic systems whose behavior is determined by interacting continuous and discrete dynamics. The continuous dynamics are described by variables taking values from a continuous set, while the discrete dynamics are described by variables taking values from a discrete, typically finite, set. We will extract Piecewise Affine (PWA) controllers which best fit the Taylor Engineering dataset. Note that here affine means “linear + constant term,” for instance a lookup table of several PI controllers + feed-forward terms is a PWA controller. PWA control systems are obtained by partitioning the input domain into a finite number of non-overlapping convex polyhedral regions, and by considering linear controllers in each region.

Measurable success criteria for correct model development will be: (1) agreement in simulations between BOMP, TOPP, and real-world data, and (2) generation of the TOPP dataset using the BOMP approach with a factor 100x speed compared to the existing TOPP procedures.

BrightBox then determined near optimal sequences that can easily be implemented based on the Taylor Engineering TOPP results using the PWA technique. The resulting near-optimal sequences were compared with the BrightBox Optimal Control results. Criteria for success were: (1) automatic quantification of error between TOPP, PWA controller, and BrightBox Optimal control performance, (2) quantified reduction of the approximation error.

Identification of BrightBox PWA controllers from TOPP datasets required the estimation of both the control parameters and the coefficients of the hyper-planes defining the partition of the state-input domain where the controller is near-optimal. The identification problem included a classification problem where each data point must be associated to the most suitable partition. When such partition is fixed a priori the classification is very simple, and estimation of the controllers can be carried out by resorting to standard linear identification techniques. When the partition is estimated along with the sub-models the regions must be shaped to the clusters of data, and the strict relation among data classification, parameter estimation and partition estimation makes the identification problem challenging. We will exploit the particular structure of the TOPP dataset and employ an iterative algorithm that sequentially estimates the parameters of the model and classifies the data through the use of adapted weights by using support vector classifiers. The proposed approach has several advantages. In fact, in addition to be systematic, model based and computationally tractable, it also provides a sub-optimality metric of the resulting PWA controller

The project goal was to achieve a 100x speed improvement in computing the current Taylor Engineering chilled-water plant optimization approach by using the Berkeley Library for Optimization Modeling (BLOM). BLOM is a language for modeling and efficiently solving optimization problems for dynamic nonlinear systems.

#### **2.1.4 AutoCx Development**

Over the course of the first two years of BrightBox software development and deployments, we realized that we needed a robust, systematic method for validating individual component configuration and operational readiness. At first we discovered these issues in an ‘indirect’ manner, by debugging system deployments when observed performance did not match the expected. There are cases where we identified component mis-configuration or equipment that was broken – and these issues were the cause of reduced performance.

AutoCx was developed in part to actively seek and discover these issues, mimicking the approach used by an operator or technician who would review an installation using the building control system interface. The basic approach is to both passively and actively read/write data to the running systems and then analyze the collected data to see if it matches expectations. Where data does not match, it indicates a system configuration or performance problem with a very low rate of false-positives.

#### **2.1.5 Commercialization**

At the time of this project, BrightBox already had an entry level commercial product at the demonstration phase in approximately 6 facilities and in early 2015 acquired the first paying customer. The product was limited to interacting with controls systems manufactured by Automated Logic Controls (Atlanta, GA) and packaged rooftop direct-exchange (DX) cooling systems, hot-water boiler plants, and variable air volume reheat (VAVR) distribution systems. As part of this project, BrightBox expanded our component library to increase our ability to model ‘built-up’ system and more complex chiller plants greatly increasing the commercialization potential.



### **2.1.6 Future potential for DoD**

The magnitude of the potential benefit we sought to demonstrate in this project for DoD was large. DoD spends approximately \$4 billion per year on facility energy consumption to power and fuel over 500 military installations worldwide. These installations include over 500,000 buildings and structures. HVAC system energy use represents roughly 40 percent of this value, which equates to approximately \$1.6 billion. A savings of 25% across this portfolio of existing buildings represents \$400 million annually.

DoD has a large number of existing buildings with packaged equipment, built-up systems, and chilled water plants of various designs and sizes that could have benefited from the BrightBox controls approach if successful. DoD facility energy expenditures at the entire NSAM site are estimated to be in the range of \$2 million per year. This approach aims to save approximately 25% of the HVAC energy used at the site in the subject buildings. We estimate the value of this savings to be approximately \$150,000 per year. If this approach was scaled to apply to the entire NSAM site, we estimate savings of approximately \$300,000 per year.

Similar savings could have been expected at other DoD installations, and for more complex buildings the values would increase. On a recent data center project with a chilled water plant of ~4,400 tons, Taylor Engineering reported that the life-cycle cost savings over 15 years were projected at \$1,500,000 using a 4.9% real discount rate.

The NSAM site is relatively small compared to other large DoD sites. The NSAM provided an excellent demonstration opportunity because of the outstanding staff, wide mix of systems, and close proximity to the BrightBox main office, but the real value to DoD will be to scale this approach to other sites that are significantly more energy intensive.

At the time of the project, the BrightBox optimization software could have been used at any DoD site that employs Automated Logic Corporation (ALC) building controls. The BrightBox product development roadmap included extending the list of control systems with which we can interact and we anticipated that the number of DoD sites where this solution can be applied would have expanded rapidly in the next few years following the project.

AutoCx could be deployed widely at DoD sites – both in new construction projects and in existing buildings. The BrightBox AutoCx software product was designed to deploy simple tests in a broad, repeatable, ubiquitous fashion. Commissioning has been called the most cost-effective energy efficiency measure available today [30], with the potential to improve operational efficiency across many building types and deployments.

## **2.2 TECHNOLOGY DEVELOPMENT**

The technology that is the subject of this project can be thought of in two parts: 1) the cloud-hosted software (the BrightBox software) that provides the advanced control and autonomous commissioning services, and 2) the building control system including the sensors and actuators that are integral to that system.

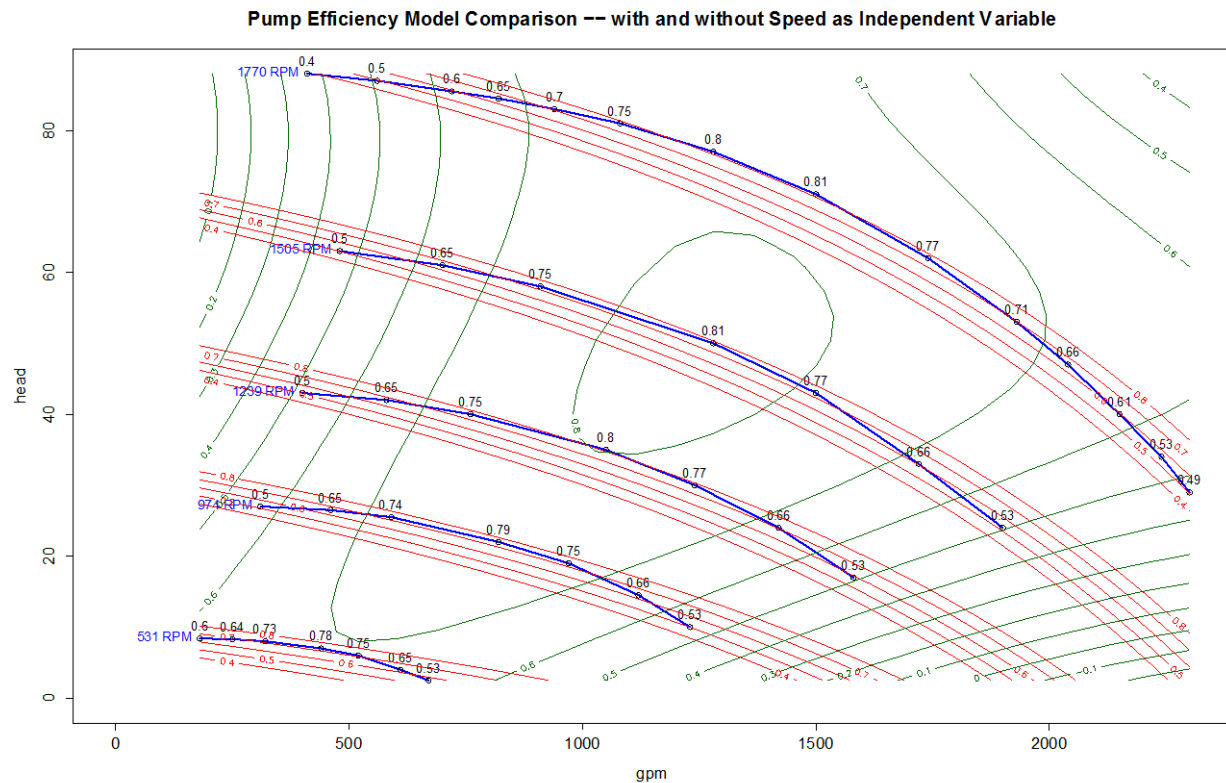
At NSAM, the building control systems in Watkins and Glasgow were augmented to provide data points required for monitoring and verification activities and calculations.

## 2.2.1 Software Technology Development

Before this project began, the BrightBox system was able to connect with, model, and provide real-time optimal control to one standard building HVAC system type: “packaged” rooftop air-conditioning units connected to a variable-air-volume reheat (VAVR) system. In order to deploy the technology at NSAM, and make it suitable eventually for other DoD sites, we needed to extend the library of components to include HVAC system types and components found at Glasgow and Watkins Hall, namely chilled-water cooling systems including air-cooled chillers and chilled-water pumps, which are components commonly found in medium to large size commercial and industrial buildings.

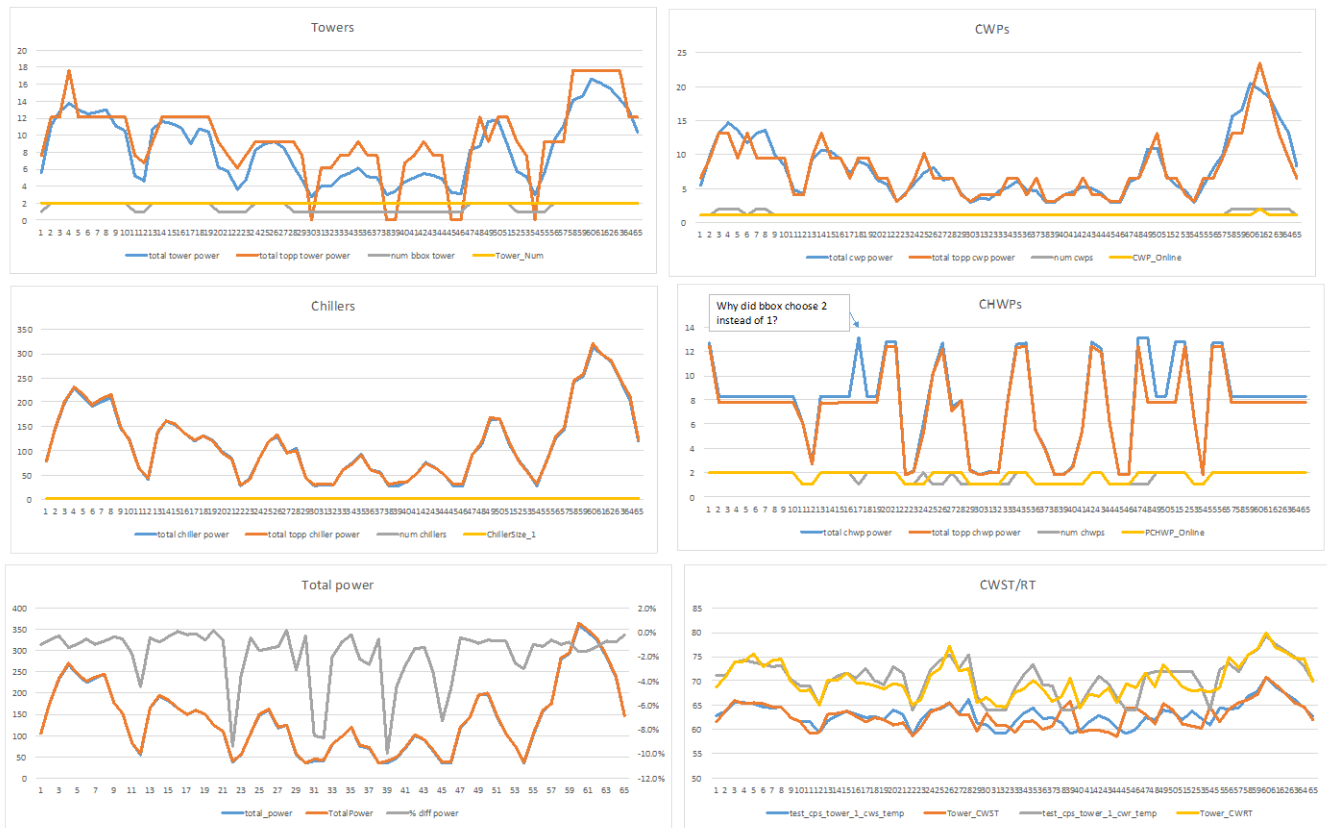
The BrightBox system software was successfully extended to include chilled water systems, air-cooled chillers, and chilled water pumps as part of this project. To validate that these new software components were implemented correctly, BrightBox software was tested against the Taylor Engineering TOPP Model Chilled-Water Plant modeling software.

The graphic below shows a performance ‘map’ for a chilled water pump software model component. Data shown in blue and black is manufacturer catalog data showing pump speed, pumping performance, and pump efficiency. The graphical data shown in red and green are two different formulations of pump efficiency models, with the difference between the two being that the red model uses pump speed as an independent variable, whereas the green model does not.



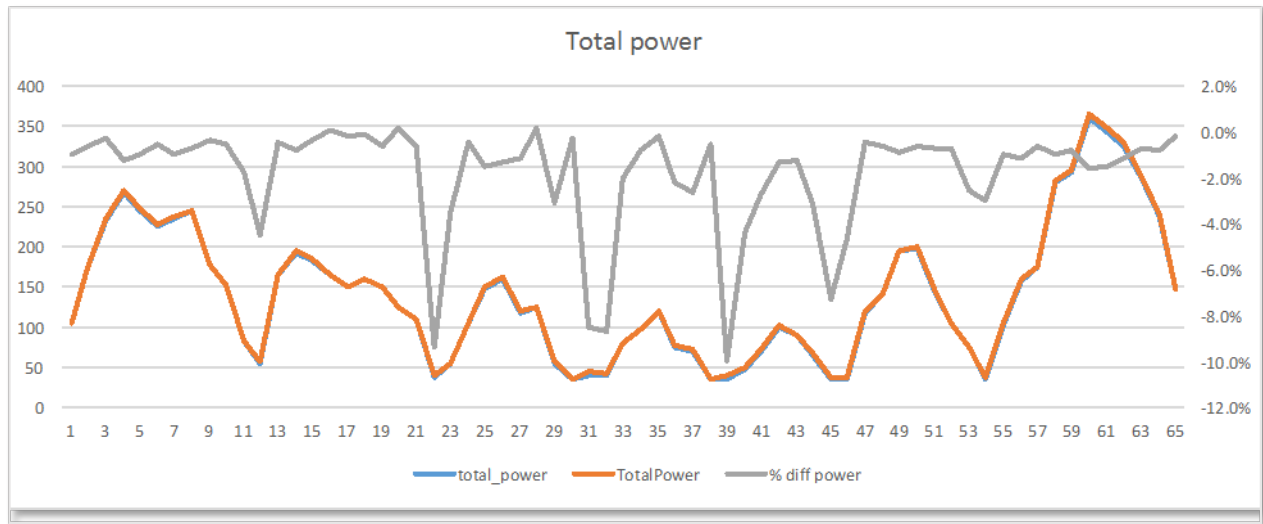
**Figure 4. BrightBox Pump Model**

The graphic below shows a comparison of the ‘BrightBox’ chilled-water plant modeling system results as compared to the Taylor Engineering ‘TOPP Model’ chilled-water plant modeling system results. Data here is broken down to show cooling tower performance, chilled-water pump performance, condenser water pump performance, and chiller performance each on separate graphs. Note that the performance is not identical in each case, but it is close enough to validate that the systems are working. The different performance is due to each modeling system arriving at optimal control decisions in a slightly different manner, with slightly different resulting final decisions.



**Figure 5. BrightBox Chilled Water Plant Modeling Comparison**

The graphic below is a ‘total plant power’ comparison between the BrightBox system and the Taylor Engineering system. In the graphic the blue line represents the BrightBox result and the orange line represents the Taylor Engineering result. The blue line is hard to see because it is directly under the orange line. The gray line shows the percent different between the two and is read on the right-side axis. Note that the gray line is always at value 0% or below, indicating that the BrightBox optimal control decision-making is better than the Taylor Engineering result in that it delivers lower total plant power to deliver the same cooling result.



**Figure 6. BrightBox Modeling Comparison Detail**

We also extended the BrightBox system user interface in a rudimentary way to allow for the inclusion of chilled-water plant systems and components. The screen below shows one example from the revised UI.

The screenshot shows the 'BrightBox - Taylor-Engineer - Chiller Plant System' interface. The 'Define a chiller plant system and run the simulation' form is active, displaying the following configuration:

Field	Value
Name*	test_cps
Chiller type*	test_chiller_design_param_lib_1
Num chiller*	2
Chw pump type*	test_chwp_design_param_lib_4
Num chw pump*	2
Cw pump type*	test_cwp_design_param_lib_1
Num cw pump*	2
Tower type*	test_tower_design_param_lib_1
Num tower*	2

**Figure 7. BrightBox Plant Modeling User Interface**

## 2.2.2 Building Control Systems Technology Development

To support chilled-water system component model development and validation as well as monitoring and verification activities, the building control systems at Glasgow and Watkins were investigated and augmented as needed to provide required sensors and data streams.

The images below show the BrightBox team investigating the site as well as existing energy meters located at the site that were going to be used as part of the study.



These are existing BTU (energy) meters on the chilled water systems.



The buildings at NSAM have AMI (Advanced Metering Initiative) electrical meters at each building, but unfortunately the connective data-network to make that data available was not functioning, so this data was not available for the project.



The following matrix shows analysis and metering-data design performed for the subject buildings. This matrix formed the basis for a substantial sensor/meter installation project that was performed in each building. A larger version of this metering plan as well as the metering installation contract documents are provided as appendices.

NSAM / NSP Chilled Water Plant Metering Plan														January 17, 2015
<div>Legend:</div> <div><div></div>required meter and data already available, no change needed</div> <div><div></div>data not available, but not required for metering plan</div> <div><div></div>required data not available, need to install sensors / meters</div> <div><div></div>data sources uncertain, need to confirm this data in the field</div>														
Building	Watkins (#245)					Ingersoll (#390)					Glasgow (#305)			
Chiller Info	Type	CH-1	CH-2	CH-3	system	CH-1	CH-2	system	CH-3	system	CH-1	CH-2	CH-3	system
Type	air-cooled	air-cooled	air-cooled	air-cooled	primary only variable flow with bypass	air-cooled	air-cooled	primary only variable flow no bypass	water-cooled	primary only constant flow	air-cooled	air-cooled	air-cooled	primary only constant flow
Manufacturer	York	York	Trane			Carrier			Trane	Trane	York	York	York	
Model	?	?	?			30-8000	?		?		YCAL?	YCAL?	YCAL?	?
Nominal Tonnage	30	30	?		60	?	?		?		?	?	?	?
Networked Controller	yes	yes	no		yes	yes	no		no		yes	yes	yes	
Server	B215	B215	B216		215+216	yes	no	main building		data center	yes	yes	yes	3103
Notes	new	new	not in the field			dates to 2008	older?							
Cooling Tower / Dry Cooler Info	Type								CU-1	primary only constant flow				
Manufacturer									Colmac					
Model									224 rpm	?				
Nominal Tonnage														
Nominal Flow														
Networked Controller									no					
Notes														
CW BTU meter	(BTU/hr) (GPM/hr)	(@system)	(@system)	(@system)	yes	no	no	no	no	no	(@system)	(@system)	(@system)	yes
CW flow	gpm	(@system)	(@system)	(@system)	yes	no	no	no	no	no	(@system)	(@system)	(@system)	yes
evaporator dpt	(F) or (psi)	yes	yes	no		yes	yes		yes		no	no	no	
CW temp	(F)	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
CW temp	(F)	yes	yes	yes	yes	(@system)	(@system)	yes	yes	yes	yes	yes	yes	yes
Auto Isolation Valve		yes	yes	no		yes	yes		no		yes	yes	yes	
Bypass / Min Flow Valve		yes	yes		yes	no	no	no						
CW BTU meter	(BTU/hr) (GPM/hr)								no	no				
CW flow	gpm								no	no	no	no		
condenser dpt	(F) or (psi)								yes	no				
CW temp	(F)								yes	yes				
CW temp	(F)								yes	yes				
Auto Isolation Valve									no					
Bypass / Min Flow Valve									yes					
Chiller Electrical Power	[W]	no	no	no		no	no		no		no	no	no	
Tower Electrical Power	[W]								no					
Notes	units	P-3 also CH-1	P-4 also CH-2	P-5 also CH-3		P-1	P-2		PCH-3 CH-W	PCH-4 CH-W	CHWP-1	CHWP-2		
Nominal Flow						160 gpm	180 gpm							
VFD	yes	yes	yes	yes		yes	yes		no	no	no	no		
Networked	yes	yes	yes	yes		yes	yes		no	no	no	no		
Current	[Amps]	yes	yes	yes		yes	yes		no	no	no	no		
speed	[Hz] or [RPM]	yes	yes	yes		yes	yes		no	no	no	no		
power	[kW]	yes	yes	yes		yes	yes		no	no	no	no		
pump on	(F) or (psi)	no	no	no		no	no		no	no	no	no		
system dpt	(F) or (psi)				yes		yes							
Notes	units								PCH-1 CH-W	PCH-2 CH-W	PAC-1 CH-W	PAC-2 CH-W		
Nominal Flow									80 gpm	80 gpm	150 gpm	150 gpm		
VFD	yes	yes	yes	yes		yes	yes		no	no	no	no		
Networked	yes	yes	yes	yes		yes	yes		no	no	no	no		
Current	[Amps]	yes	yes	yes		yes	yes		no	no	no	no		
speed	[Hz] or [RPM]	yes	yes	yes		yes	yes		no	no	no	no		
power	[kW]	yes	yes	yes		yes	yes		no	no	no	no		
pump on	(F) or (psi)								no	no	no	no		
system dpt	(F) or (psi)													

This is a list of the points added to the subject systems:

Watkins Hall (Building 245)

- CH-1 (air cooled)
  - Power meter (Veris, Modbus)
- CH-2 (air cooled)
  - Power meter (Veris, Modbus)
- CH-3 (air cooled)
  - Power meter (Veris, Modbus)
  - Evaporator dp sensor  
(field verify if new pipe taps required)
- P-3 (CHW pump)
  - Inlet/outlet dp sensor  
(field verify if new pipe taps required)
- P-4 (CHW pump)
  - Inlet/outlet dp sensor  
(field verify if new pipe taps required)
- P-5 (CHW pump)
  - Inlet/outlet dp sensor  
(field verify if new pipe taps required)
- FC-2-E
  - CHW coil dp sensor  
(field verify if new pipe taps required)
  - CHWS temperature sensor
  - CHWR temperature sensor
- AH-3-2
  - CHW coil dp sensor  
(field verify if new pipe taps required)
  - CHWS temperature sensor
  - CHWR temperature sensor

Ingersoll Hall (Building 330) – Main Building System

- CH-1 (air cooled)
  - Power meter (Veris, Modbus)
- CH-2 (air cooled)

- Power meter (Veris, Modbus)
- P-1 (CHW pump)
  - Inlet/outlet dp sensor  
(field verify if new pipe taps required)
- P-2 (CHW pump)
  - Inlet/outlet dp sensor  
(field verify if new pipe taps required)
- SF-2 (CHW AHU with cooling)
  - Branch-1 HW coil
    - dp sensor
    - HWS temp sensor
    - HWR temp sensor
  - Branch-2 HW coil
    - dp sensor
    - HWS temp sensor
    - HWR temp sensor
  - Branch-3 HW coil
    - dp sensor
    - HWS temp sensor
    - HWR temp sensor
- SF-2 (CHW AHU with cooling)
  - CHW coil dp sensor  
(field verify if new pipe taps required)
  - CHWS temperature sensor
  - CHWR temperature sensor
  - SF-2 Power Meter (Veris, Modbus)
  - EF-3 Power Meter (Veris, Modbus)

#### Ingersoll Hall (Building 330) – Data Center System

- CH-3 (water cooled)
  - Power meter (Veris, Modbus)
  - CHW BTU meter
    - Flow meter (insertion-type, mag flow, Onicon)
    - New CHWS and CHWR sensors
- PCH-3 (CHW pump)
  - Power meter (Veris, Modbus)
  - Inlet/outlet dp sensor  
(field verify if new pipe taps required)



- PCH-4 (CHW pump)
  - Power meter (Veris, Modbus)
  - Inlet/outlet dp sensor  
(field verify if new pipe taps required)
- CU-1 (dry cooler)
  - Power meter (Veris, Modbus)
  - CW BTU meter (total CW flow = CH-3 branch + CRAC branch)
    - Flow meter (insertion-type, mag flow, Onicon)
    - New CWS and CWR sensors
- PCH-1 (CW pump – CH-3 branch)
  - Power meter (Veris, Modbus)
  - Inlet/outlet dp sensor  
(field verify if new pipe taps required)
- PCH-2 (CW pump – CH-3 branch)
  - Power meter (Veris, Modbus)
  - Inlet/outlet dp sensor  
(field verify if new pipe taps required)
- PAC-1 (CW pump – CRAC branch)
  - Power meter (Veris, Modbus)
  - Inlet/outlet dp sensor  
(field verify if new pipe taps required)
- PAC-2 (CW pump – CRAC branch)
  - Power meter (Veris, Modbus)
  - Inlet/outlet dp sensor  
(field verify if new pipe taps required)
- CW BTU meter (CRAC branch)
  - Flow meter (insertion-type, mag flow, Onicon)
  - New CWS and CWR sensors

#### Glasgow Hall (Building 305)

- CH-1 (air cooled)
  - Power meter (Veris, Modbus)
  - Evaporator dp sensor  
(field verify if new pipe taps required)
- CH-2 (air cooled)
  - Power meter (Veris, Modbus)

- Evaporator dp sensor  
(field verify if new pipe taps required)
- CH-3 (air cooled)
  - Power meter (Veris, Modbus)
  - Evaporator dp sensor  
(field verify if new pipe taps required)
- CHWP-1 (CHW pump)
  - Power meter (Veris, Modbus)
  - Inlet/outlet dp sensor  
(field verify if new pipe taps required)
- CHWP-2 (CHW pump)
  - Power meter (Veris, Modbus)
  - Inlet/outlet dp sensor  
(field verify if new pipe taps required)
- FC-B-06
  - CHW coil dp sensor  
(field verify if new pipe taps required)
  - CHWS temperature sensor
  - CHWR temperature sensor
- FC-B-09
  - CHW coil dp sensor  
(field verify if new pipe taps required)
  - CHWS temperature sensor
  - CHWR temperature sensor
- FC-1-03
  - CHW coil dp sensor  
(field verify if new pipe taps required)
  - CHWS temperature sensor
  - CHWR temperature sensor

## **2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY**

### **2.3.1 Performance Advantages**

The goal for the BrightBox HVAC optimization technology was to increase energy efficiency by providing optimized control sequence of operation for existing controls infrastructures by updating optimized HVAC control algorithms quickly and on a regular basis (typically every 5 minutes).

### **2.3.2 Cost Advantages**

As a software solution, BrightBox offers very low up first costs. Current typical sales cycles involve an offer of a no-cost demonstration to show what the BrightBox software can do and once energy savings have been quantified, the savings are shared between BrightBox and the customer so both parties share the savings.

AutoCx delivers the benefits of commissioning to new and existing buildings at a greater than 10x reduction in cost over traditional commissioning deployment methods.

### **2.3.3 Performance Limitations**

BrightBox currently works only by optimizing the controls of existing HVAC equipment. Energy saving performance could be improved by expanding the BrightBox approach (for customers where it makes economic sense) to also retrofitting and changing installed HVAC equipment. Currently, BrightBox only works with HVAC control systems manufactured by Automated Logic Controls (A subsidiary of United Technologies). In its current form, an active internet connection is required to implement the BrightBox optimization. Future releases may include standalone or non-internet enabled solutions that may be applicable specifically in the highly secure DoD networks.

One significant limitation to deploying this technology became clear over the course of this project. The BrightBox optimization system requires the base building systems and components to be installed and working correctly in order for it to function properly. As we found out with the Glasgow chillers, if the equipment is not installed or operating correctly then those issues must be resolved first before any optimization can occur.

### **2.3.4 Cost Limitations**

We don't see any cost limitations with the BrightBox approach because we demonstrate cost savings first and then charge a portion of the savings for providing the service. Both the customer and BrightBox achieve a positive economic result using this approach.

### **2.3.5 Potential Barriers to Acceptance**

Few barriers have arisen regarding the product and technology in the commercial sector. Every building operator we have encountered in the course of launching the BrightBox service embraces the idea that BrightBox can provide optimized HVAC controls algorithms. Early reports indicated that the building operators wanted a big button to turn BrightBox optimization off first if complaints or problems occur – so we now have a big “off” button integrated into the ALC interface for the BrightBox client software.

However, several barriers exist with respect to wide-spread DoD implementation of BrightBox HVAC optimization.

1. The recent hacking of Target Co. customer credit card information via a third-party HVAC contractor has raised concerns within all Federal agencies (not just DoD) regarding providing any outside contractor with direct access inside a secure network.

2. Although BrightBox is working to expand our product offering to additional controls platforms, currently the BrightBox optimization only works in buildings equipped with Automated Logic Controls (ALC)
3. Many DoD buildings would require extensive infrastructure upgrades to legacy/outdated/ or non-existent BAS in order for HVAC data analytics solutions such as BrightBox optimization to be deployed.

### **3.0 FACILITY/SITE DESCRIPTION**

Home to over 15 tenant commands, NSAM Monterey (Monterey, CA) provides primary support to the Naval Postgraduate School (NPS), Navy Research Lab (NRL), and the Fleet Numerical Meteorology and Oceanography Center (FNMOC). NPS is the largest producer of advanced graduate degrees for the Department of Defense and proudly graduates thousands every year from all services and from over 50 countries. NRL provides all scientific and weather modeling as well as atmospheric and aerosol studies. FNMOC provides the highest quality, most relevant and timely worldwide Meteorology and Oceanography support to U.S. and coalition forces from FNMOC's 24x7 Operations Center in Monterey. NSA Monterey supports over 160 buildings which are located on more than 626 acres.

### **3.1 GENERAL FACILITY/SITE SELECTION CRITERIA**

#### **3.1.1 Geographic Criteria**

There are no geographic criteria that impact whether or not this technology can be deployed. It can be applied to any HVAC system in any climate. At the same time, it likely makes more sense to deploy this type of energy efficiency technology in climates with high cooling and/or heating demands in order to maximize returns from the time and effort involved in deploying the system.

#### **3.1.2 Facility Criteria**

Because the current BrightBox technology addresses only packaged rooftop direct-exchange (DX) cooling systems, hot-water boiler plants, and variable air volume reheat (VAVR) distribution systems, we wanted to find a facility with a more 'built-up' chilled water plant. But it was also important that it not be too complicated. We wanted to find one or more buildings with relatively simple chilled water plants to extend the technology.

#### **3.1.3 Facility Representativeness**

Facility representativeness was not a factor. DoD has a large number of existing buildings with packaged equipment, built-up systems, and chilled water plants of various designs and sizes that can benefit from the BrightBox controls approach.

#### **3.1.4 Other Selection Criteria**

It was important to BrightBox to do the demonstration project in a relatively low security DoD environment both physically and electronically. Because BrightBox is a software solution, we need access to the HVAC controls via the internet through firewalls etc. A facility that was electronically isolated or 'locked-down' would not work at this stage. We are aware that most other DoD facilities are more secure and that we will need to develop a 'box on site' solution if we expect significant penetration into the DoD market.

During this project, the cyber-security awareness at NSAM was increased substantially and it moved from being a relatively 'open' system to one that implemented many standard DoD policies. As part of this escalation, a thorough cyber-security audit was performed and all of the operational BrightBox system components continued to function and passed the audit review.

Because the BrightBox system was not specifically evaluated during this review, it was not determined whether the system met the RMF requirements or if an Interim Authority To Test (IATT) was attained.

### 3.2 DEMONSTRATION FACILITY/SITE LOCATION AND OPERATIONS

The demonstration site was Naval Support Activity Monterey (NSAM). The largest tenant of NSAM is the Naval Post Graduate School (NPS). We chose two buildings assigned to the NPS for the demonstration project.

#### 3.2.1 Demonstration Site description

NSAM is located relatively close (less than a 2-hour drive) to the BrightBox Technologies office in Berkeley, California, which will facilitate easy interaction with site staff and BrightBox presence on the campus as needed. Further, NSAM is served by Sunbelt Controls, a controls contractor partner of BrightBox Technologies and collaborator/channel-partner of our technology platform. Sunbelt Controls has been engaged as an active partner in the proposed ESTCP project, and they will be a valuable, knowledgeable, and capable partner in this effort.

The HVAC systems at NSAM are largely controlled with Automated Logic Corporation (ALC) control hardware and software. BrightBox Technologies has partnered with ALC to provide our software as an integrated “plug-in” to the ALC system.

BrightBox Technologies staff have corresponded with and visited NPS staff, including Public Works Officer LCDR Antillon, Deputy Public Works Officer Matthew Suess, Ken Jenvey APPS Support Contractor for NAVFAC SW (since replaced by Douglass Taber) and other key members of the operations staff. We have a good understanding of the systems in place and NSAM and, in collaboration with NSAM staff, have identified the following likely subject buildings for our demonstration. These buildings represent a wide range of systems, components, and HVAC design approaches onto which we can deploy the BrightBox optimal control approach to demonstrate the technology’s broad range of applicability.

Name & Main Uses	Cooling Systems	Zonal Systems	Existing Metering
<u>Glasgow Hall</u> <ul style="list-style-type: none"> <li>Computer Science Department</li> </ul>	System 1: 3 x 60-ton air-cooled chillers, 2 headered CHW pumps, constant-speed variable-flow primary-only configuration System 2: 2 x 50-ton air-cooled chillers with dedicated constant speed CHW pumps and CHW system bypass	2-pipe CHW fan coils, 4-pipe CHW & HW fan coils, CAV reheat, 2-stage packaged cooling-only AC unit with economizer, large built-up AHU with “fan wall,” HW, CHW, and economizer	System 1 and System 2 CHW & HW system flow and BTU meters, building steam meter, building power meter
<u>Watkins Hall</u> <ul style="list-style-type: none"> <li>Building 245</li> </ul>	System 1: single chilled water system, 3 air-cooled chillers @30 tons each. 3 headered chilled water pumps with variable flow. Primary only configuration	2-pipe and 4-pipe systems, a mixture of zonal fan coils with and without economizers and VAV ‘cooling only’ along with some reheat zones	Existing chilled water BTU meter, building power meter.

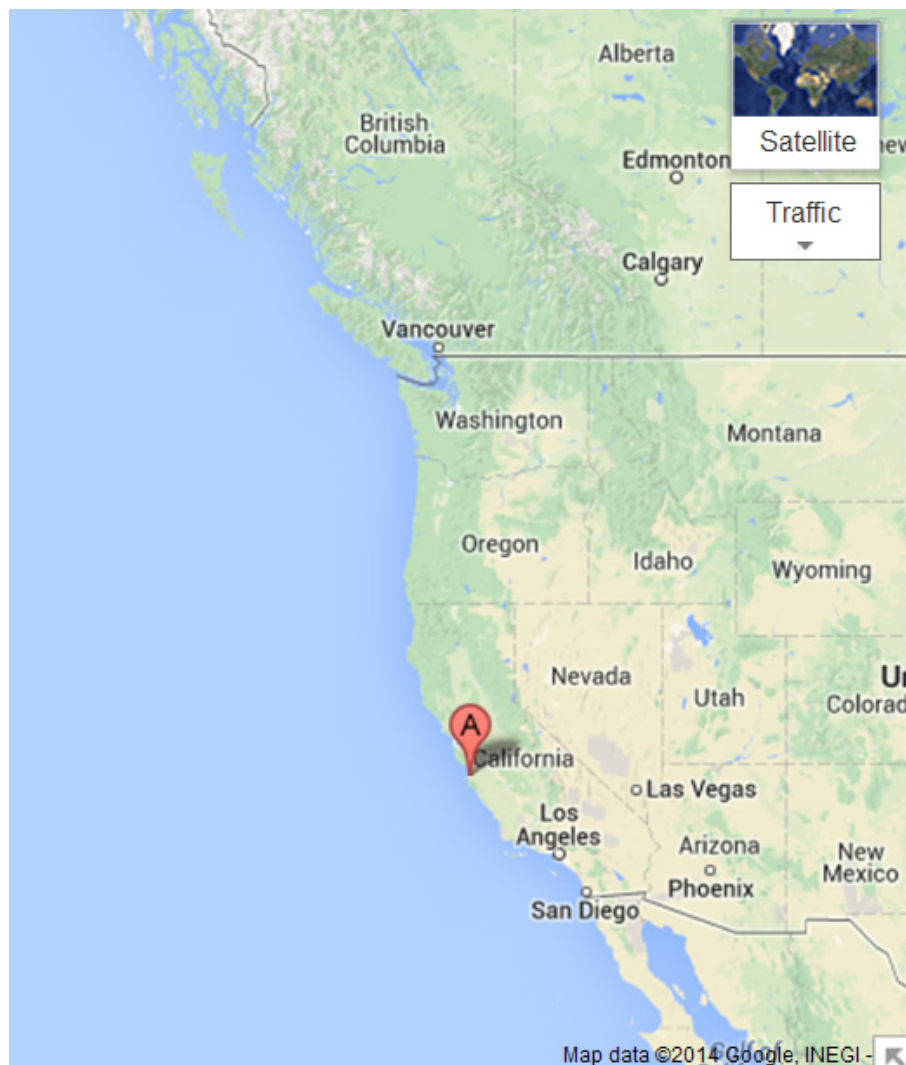
\*\*In our original proposal, Ingersoll Hall was also included as a test site. However, as we initiated the demonstration, we found out that Ingersoll Hall is scheduled for a major physical retrofit that precludes the implementation of the BrightBox Optimization during the ESTCP project timeframe. Correspondence documenting electronic transmissions regarding the retrofit and subsequent acceptance by ESTCP management of a two building EW201409 demonstration project are attached as Appendix E.

### 3.2.2 Key Operations

NSAM supports the Naval Post Graduate School (NPS), Navy Research Lab (NRL), and the Fleet Numerical Meteorology and Oceanography Center (FNMOC).

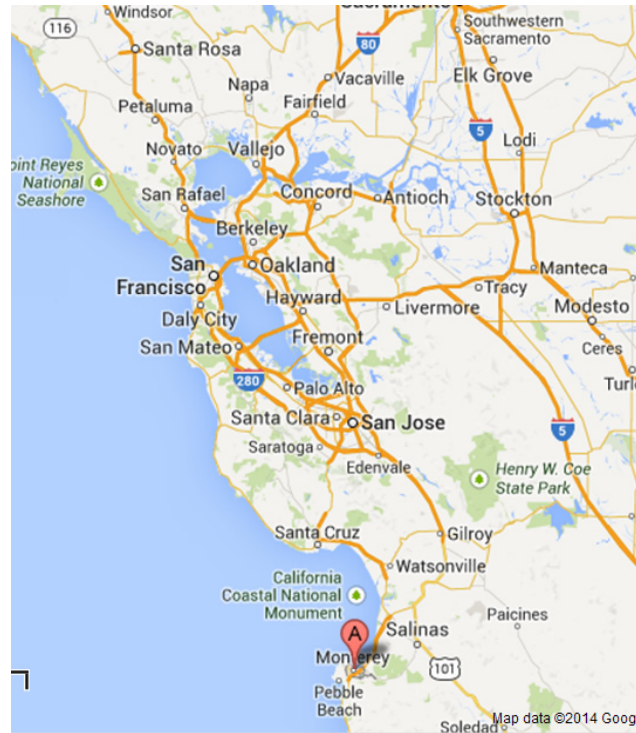
### 3.2.3 Location/Site Map

#### 3.2.3.1 General location in California.



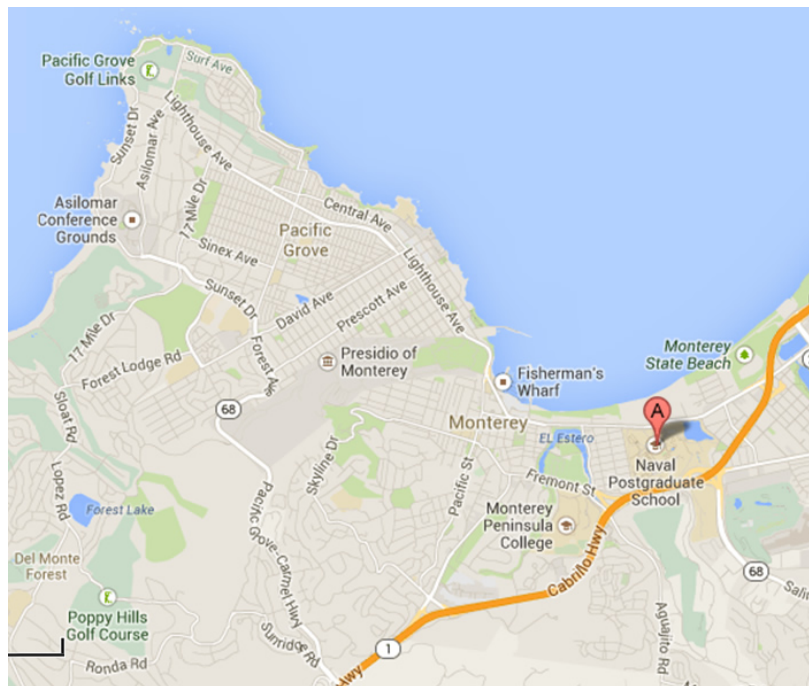
**Figure 8. Location in California**

### 3.2.3.2 Location in San Francisco Bay Area



**Figure 9. Location in San Francisco Bay Area**

### 3.2.3.3 Location in Monterey



**Figure 10. Location in Monterey**



### 3.2.4 NSAM map

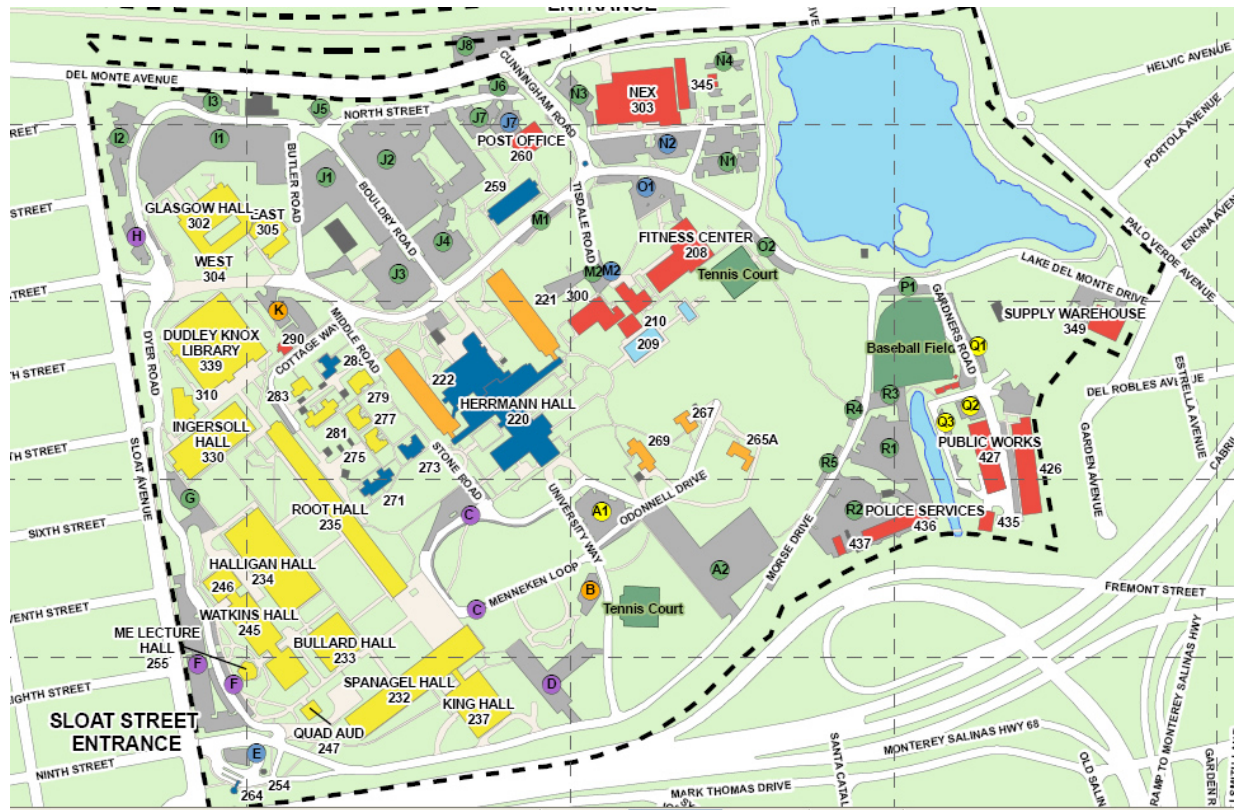


Figure 11. NSAM map

### 3.3 SITE-RELATED PERMITS AND REGULATIONS

Because BrightBox is a software solution, no site-related permits will be required during the course of this demonstration project.

### 3.4 REGULATIONS

No regulations that we are aware of.

#### 3.4.1 Environmental Permits

No environmental permits required that we are aware of.

#### 3.4.2 Agreements

No agreements were required to perform the technology deployment at NSAM. The key point of contact was the NSAM Public Works Officer who is LCDR Oscar Antillion. LCDR Oscar Antillion participated in the site visit meeting that occurred between BrightBox Technologies, Taylor Engineering, Sunbelt Controls, and NSAM personnel at NSAM on July 18<sup>th</sup>, 2014. LCDR Oscar Antillion was very encouraging and specifically expressed the sentiment that NSAM would be supportive of the project and that they were excited to be testing the latest technology at their facility and welcomed the opportunity to lead the Navy.

### **3.4.3 Military Requirements**

Information assurance has been identified as serious obstacle to rolling out BrightBox Technologies product in its current form to other DoD facilities. In fact, NSAM personnel during the first site visit suggested that if the team could design a solution to successfully overcome the information assurance obstacles as part of this project, that would be a very welcome outcome.

However, information assurance is not a problem at the NSAM site. We have already been granted remote access to the NSAM building control systems that we need for the project.

As mentioned above, the cyber-security concerns at NSAM escalated during the course of the project. The BrightBox encrypted data connection (outbound-only using HTTPS) passed the security review, which was a very positive result.

### **3.5 Property Transfer**

As part of this demonstration project, we installed end-use power/fuel meters at key pieces of equipment in the buildings and integrate these new meters into the existing control system. Now that the project is complete, these meters will remain in place and operational and will become DoD property.

NSAM expressed their desire to leave all meters in place. We intentionally installed them in an integrated manner with the existing building control systems so they could be left in place and continue to operate with no disruption to the buildings.

## 4.0 PERFORMANCE OBJECTIVES

We set performance objectives for this project based on our experience to date in commercial buildings. The BrightBox software solution has been deployed in roughly a dozen commercial buildings and we have achieved savings of 20% to 35% of HVAC energy. This experience is restricted to packaged HVAC units, not chiller plants. An objective of the current project was to extend the BrightBox system to include built-up chiller plants so naturally we do not have any existing data. Therefore, it makes sense to set the energy objective at the low end of the range – 20% of HVAC energy.

The site has a number of meters in place in each building so we won't be increasing the number of metered buildings. However, we plan to add specific meters according to the following plan:

Glasgow Hall:

- Three (3) Veris Modbus Power Meters, One (1) for each Chiller
- Three (3) Chiller Evaporator DP Sensors, One (1) for each Chiller
- Two (2) Veris Modbus Power Meters, One (1) for each Chilled Water Pump
- Two (2) Chilled Water Pump DP Sensors, One (1) for each Pump

Watkins Hall:

- Three (3) Veris Modbus Power Meters, One (1) for each Chiller
- One (1) Chiller Evaporator DP Sensor for Chiller #3
- Three (3) Chilled Water Pump DP Sensors, One (1) for each Pump
- One (1) FC-2-E Chilled Water DP Sensor
- Two (2) FC-2-E Chilled Water Temperature Sensors (strap-on sensors)
- One (1) AH-3-2 Chilled Water DP Sensor
- Two (2) AH-3-2 Chilled Water Temperature Sensors (strap-on sensors)
- Two (2) Chilled Water Strap-on Sensors located next to two (2) existing well sensors for lag comparison. Location to be determined (B233 Chiller is the first choice)

We don't currently have any sub-metering information available to make a system economic analysis of the potential economic savings at the start of the project. We only have electric bill information for the one meter that serves the entire NSAM site. We have no information on energy consumption or costs available for any of the individual buildings. As we get into the project, monitor the buildings and apply the BrightBox technology, we will begin to be able to provide estimates of the system economics. However, we project that a 20% reduction in energy use should lead to a reduction in energy costs of a similar amount – 20%.

We are fortunate that we can turn the BrightBox software on and off remotely whenever we want. This allows us to continuously collect baseline data. Baseline data is whatever the system is doing when the BrightBox software is turned off.

The goal was for the BrightBox system to increase energy security at NSAM (and potentially other military installations in the future) by reducing energy density. BrightBox will contribute to cost avoidance reducing energy usage. The goal was for the BrightBox system to contribute to reducing GHG emission by reducing energy usage.

#### 4.1 “TABLE 1” SUMMARY OF PERFORMANCE OBJECTIVES

##### 4.1.1 Table 1. BrightBox Performance Objectives – ESTCP 201409

**Table 1. Performance Objectives**

Performance Objective	Metric	Data Requirements	Success Criteria	Results
<b>Quantitative Performance Objectives</b>				
Facility Energy Usage	Energy Intensity (kWh/ft <sup>2</sup> )	Meter readings of energy used by installation; square footage of buildings using energy; sub-metered HVAC system data	20% Reduction in HVAC system energy use compared to baseline, 7.5% reduction in overall energy use.	No data collected. Demonstration not performed.
System Economics*	Savings to investment ratio (SIR)	Measured reduction in HVAC system energy costs	SIR >= 1.67**	No calculation performed.
BOMP Library Expansion	Number of BOMP Library Components	Number of BOMP Library Components	Expand the BOMP component library to include 13 new components	Only hydronic components completed (5 of 13)
BrightBox Control Software Generation	Models Generated	Models Generated	The BrightBox software will be able to successfully generate new control software automatically for each of the two buildings.	Completed in simulation, not deployed.
TOPP model dataset generation speed	Time to generate TOPP model data	Time to generate TOPP model data using BrightBox platform and Taylor platform	100x improvement in the time to generate TOPP model data using the BrightBox platform versus the Taylor platform.	TOPP data set generation and BrightBox solution generation roughly same time to complete. No improvement.
AutoCx number of objects tested and number of issues found	Number of objects tested and number of issues found	Number of objects tested and number of issues found	All testable objects at the demonstration site have been tested and number of issues found has been field verified.	Half of testable objects tested.
<b>Qualitative Performance Objectives</b>				
Satisfaction with BrightBox Control Software	Facility Surveys (a sample survey is provided in Appendix C)	Positive Responses on User Surveys	Based on survey responses, the facilities staff at NSAM indicate that they feel the new control sequences generated by the BrightBox software are adequate/functional and will remain in use.	No surveys issued.

\*For “System Economics” - Refer to the NIST Building Life Cycle Cost program, available on the DOE website: [http://www1.eere.energy.gov/femp/information/download\\_blcc.html#blcc](http://www1.eere.energy.gov/femp/information/download_blcc.html#blcc)

\*\* We don’t currently have any sub-metering information to use to make a system economic analysis of the potential economic savings at the start of the project. We only have electric bill information for the one meter that serves the entire NSAM site. We have no information available for any of the individual buildings. As we get into the project, monitor the buildings and apply the BrightBox technology, we will begin to be able to provide estimates of the system economics.

## **4.2 PERFORMANCE OBJECTIVES DESCRIPTIONS**

### **4.2.1 Facility Energy Usage**

#### ***4.2.1.1 Purpose***

Reduce facility energy usage via the BrightBox HVAC control optimization application.

#### ***4.2.1.2 Metric***

Measured facility energy usages (kWh) with the BrightBox application running compared to the with the BrightBox application not running (kWh).

#### ***4.2.1.3 Data***

Data collected using the BrightBox system from the HVAC controls systems at the NSAM site. Data from energy and power meters installed on HVAC equipment at the NSAM site.

#### ***4.2.1.4 Analytical methods***

Graphs and tabulations comparing baseline HVAC system performance compared to HVAC system performance with the BrightBox application in operation. These data will be adjusted for load and weather differences.

#### ***4.2.1.5 Success Criteria***

If the HVAC energy savings meet or exceed 20% of the baseline, we have succeeded.

### **4.2.2 System Economics**

#### ***4.2.2.1 Purpose***

To reduce facility energy costs.

#### ***4.2.2.2 Metric***

The metric will be Savings to Investment Ratio (SIR)

#### **4.2.2.3 Data**

The data will be the computed savings in dollars while the investment is the cost that NSAM would pay for the BrightBox service if it were being purchased commercially.

#### **4.2.2.4 Analytical methods**

SIR is a simple ratio.

#### **4.2.2.5 Success Criteria**

We will have been successful if we produce a SIR in excess of 1.67.

### **4.2.3 BOMP Library Expansion**

#### **4.2.3.1 Purpose**

To add library components to BOMP that allow the modeling of HVAC system components.

#### **4.2.3.2 Metric**

Number of components

#### **4.2.3.3 Data**

Number of components

#### **4.2.3.4 Analytical methods**

Not applicable

#### **4.2.3.5 Success Criteria**

We will be successful if we add the following 13 BOMP components.

- “Built Up” Air-Handling Units, including the following components
  - Economizers
  - Chilled Water Coils
  - Supply Fans
  - Return Fans
  - Relief Fans
  - Variable-Frequency Drives serving any of the fans listed above
- “Built Up” Hydronic Systems, including the following components
  - Air-Cooled Chillers
  - Single-Speed Pumps
  - Variable-Speed Pumps, served by a variable-frequency drive

- Primary / Secondary Pumping Configurations
- Primary-Only Pumping Configurations
- Zone HVAC Systems, including the following
  - 2-Pipe Fan Coil Units (cooling only)
  - 4-Pipe Fan Coil Units (both heating and cooling)

#### **4.2.4 BrightBox Control Software Generation**

One key to wide deployment is not just the ability to generate models but to generate them quickly and easily. We do keep track of time to deploy broken down by hours and tasks. BrightBox has a library of components that can be assigned to a model. A software wizard searches the library to find the best component matches to the model and builds the model. Then we use field data to calibrate the model.

##### **4.2.4.1 Purpose**

To evaluate overall operation of the BrightBox software

##### **4.2.4.2 Metric**

Is the BrightBox software operating properly?

##### **4.2.4.3 Data**

Are HVAC system control setpoints and reset signals being generated and pushed into the HVAC control system at the two NSAM buildings?

##### **4.2.4.4 Analytical methods**

Not applicable.

##### **4.2.4.5 Success Criteria**

We will be successful if HVAC system control sequences are being generated and pushed into the HVAC control system at the two NSAM buildings.

#### **4.2.5 TOPP Model Dataset Generation Speed**

##### **4.2.5.1 Purpose**

To evaluate whether the BrightBox model development approach is faster than the Taylor TOPP model approach.

##### **4.2.5.2 Metric**

Is the BrightBox software model development approach faster than the Taylor TOPP model approach?

#### **4.2.5.3 Data**

Hours spent by programmer/analysts to develop models.

#### **4.2.5.4 Analytical methods**

Not applicable.

#### **4.2.5.5 Success Criteria**

We will be successful if the BrightBox models are developed faster than the Taylor TOPP models.

### **4.2.6 AutoCx**

#### **4.2.6.1 Purpose**

To evaluate the success of AutoCx as a diagnostic tool for this demonstration project

#### **4.2.6.2 Metric**

Did AutoCx test all testable objects at the buildings included in the demonstration project?

Were all issues found by AutoCx field verifiable on the actual equipment?

#### **4.2.6.3 Data**

Counts of testable equipment and tested equipment. Counts of issues reported by AutoCx and field verified issues.

#### **4.2.6.4 Analytical methods**

Not applicable

#### **4.2.6.5 Success Criteria**

We will be successful if all testable objects at the demonstration site are tested by AutoCx and all issues reported by AutoCx are verified by field inspection.

### **4.2.7 Satisfaction with BrightBox Control Software**

#### **4.2.7.1 Purpose**

To evaluate whether the facility staff are satisfied with the installation and operation of the BrightBox software.



#### **4.2.7.2 *Metric***

Are the facility staff satisfied with the BrightBox software as expressed in responses to a series of survey questions?

#### **4.2.7.3 *Data***

Answers to survey questions (a sample survey is provided as Appendix C)

#### **4.2.7.4 *Analytical methods***

Not applicable.

#### **4.2.7.5 *Success Criteria***

We will be successful if a majority of the answers to the survey questions are positive in nature.

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## 5.0 TEST DESIGN

The test design is as follows. Currently HVAC systems in two buildings at NSAM are operating with traditional controls systems. Such systems are reactive in the sense that components react to “state” signals from other components in a control sequence. BrightBox will implement a different control approach based on predictive control. The test design centers around comparing energy consumed by the HVAC systems when the traditional reactive control sequences are operating to energy consumed when the new predictive control sequences are operating.

- Fundamental Problem: The fundamental problem is that traditional HVAC system controls are reactive and do not use models of equipment performance when controlling building systems. BrightBox software optimization based on model predictive control is a new approach to HVAC control that will replace older traditional methods of HVAC control. Also fundamental is creating a software model within which this optimization of HVAC system controls can exist and evolve.
- Demonstration Question: The demonstration question is: “Can BrightBox software optimization using model-based predictive control be extended to ‘built-up’ chiller plants in an HVAC system and also save 20% of HVAC energy consumption in two buildings at NSAM?”

### 5.1 CONCEPTUAL TEST DESIGN

Conceptually, the test design is that we will measure the energy consumed by HVAC equipment in two buildings at NSAM with the BrightBox software optimization running and also not running. Power consumption, supply and return air and water temperatures, flow rates, fan speeds will also be measured and used in the model.

#### 5.1.1 Hypothesis

BrightBox software optimization can save 20% of HVAC energy consumption in two buildings at NSAM.

#### 5.1.2 Independent Variable

The independent variable is: The state of the BrightBox optimization software (on or off).

#### 5.1.3 Dependent Variable

The dependent variable is: The amount of energy consumed by the HVAC equipment.

#### 5.1.4 Controlled Variables

There are several controlled variables in the test design:

The first controlled variable is the size of the buildings. During the course of the project we will not make any physical modifications to the buildings.

The second controlled variable is the NSAM installed HVAC equipment. BrightBox is a software-only solution so the mechanical equipment will not be modified or changed in any way. Any modifications or significant maintenance (filter changes, coil replacements/flushing etc.) that could alter system performance will be documented and incorporated into our final report analysis.

The third controlled variable is the internal setpoints for temperature and humidity in the NSAM buildings.

Building occupancy is an important variable that we cannot control. However a primary input to the model is thermal load which is a proxy for building occupancy. We use thermal load to learn the historical behavior of each zone. In fact, in our approach, thermal load is a more fundamental component in the model than occupancy data could be.

A final controlled variable is the state of the components in the HVAC system. AutoCx will be used to validate the configuration and operational readiness of a number of HVAC system components. If AutoCx identifies any issues that require remediation, those issues will be assessed to determine the cost to remedy. Where costs are reasonable (no-cost or low-cost) the issues identified by AutoCx will be addressed.

### **5.1.5 Test Design**

The test design is a standard baseline/intervention test design. How much energy do the HVAC systems in these two buildings at NSAM consume without the BrightBox software optimization running versus how much energy do the HVAC systems in these two buildings at NSAM consume with the BrightBox software optimization running?

It has been noted that equipment cycling and runtime can have a significant impact on energy performance. BrightBox will maintain trend data to track compressor cycling and create tracking metrics for how the HVAC system operates with BrightBox on versus BrightBox off. These data will be available for networked chillers only: including Watkin Hall chillers 1 and 2 and Glasgow Hall chillers 1,2 and 3. Watkins Hall chiller #3 does not have a network controller.

### **5.1.6 Test Phases**

The first phase is to collect some baseline data using metering equipment that is already installed. At the time of this writing, the ALC Webcntrl platform at NSAM has been upgraded but there is still an HTTPS certificate problem that prevents remote data collection. The problem is that HTTPS communication can only occur between servers with authenticated certificates and the NSAM server lacks the authenticated certificate. NSAM is working on this problem.

When the HTTPS certificate problem has been fixed, we will remotely monitor all data available in the ALC system for regular operation of the HVAC system including zone temperatures, existing power meters and chilled water flow.

Please see Appendix D for the NSAM/NPS Chilled Water Plant metering plan and associated metering installation request document provided to our subcontractor Sunbelt Controls.

After the new models of the chiller plants have been developed by the BrightBox engineering team, the next phase is to roll-out the software and verify that the optimization is functioning correctly. The next phase is to collect data with the BrightBox optimization software operating and not operating to compare the two conditions. The last phase is to analyze this data.

## **5.2 BASELINE CHARACTERIZATION**

The baseline characterization will constitute periods of time when the BrightBox optimization software is not operating compared to periods of time when the BrightBox software is operating. We anticipate that several days to a week in each mode will provide good baseline-to-test mode ratio data.

### **5.2.1 Reference Conditions**

Reference conditions are designated to be conditions when the BrightBox optimization software is not operating. Retrospectively, reference conditions will be designated as periods of time when the BrightBox optimization software is not operating where similar weather and loads occurred compared to a period when the BrightBox optimization software was operating

### **5.2.2 Baseline Collection Period**

Baseline data collection has already begun to understand how these buildings operate. Baseline data for quantitative calculations to support the objectives of the project will be collected concurrently with the test data by turning the BrightBox optimization software on and off and observing HVAC system energy consumption in similar weather conditions.

### **5.2.3 Existing Baseline Data**

No existing baseline data exists. We only have some recent utility data for one meter that serves the entire NSAM site of roughly 30 buildings. We have no existing data specifically for the two buildings we intend to focus on for this project.

### **5.2.4 Baseline Estimation**

We don't have a reliable baseline estimation that we can provide in advance. However, during the course of the project we will be collecting baseline data continuously during the course of the project during periods when the BrightBox software optimization is turned off.

### **5.2.5 Data Collection Equipment**

The buildings at NSAM have some metering equipment installed. We intend to install additional meters to measure power and energy consumption, supply and return air and water temperatures, and flow rates. The facility already has HVAC controls provided by Automated Logic Controls (ALC) and we intend to upgrade the ALC controls to the latest version and connect any new metering equipment to the upgraded ALC system.

## 5.3 DESIGN AND LAYOUT OF SYSTEM COMPONENTS

### 5.3.1 System Design

The system design centers around remotely administered model-based HVAC controls optimization. The system replaces reactive HVAC controls (controls that react to various inputs) with a predictive model that anticipates how the HVAC system will need to operate based on various data inputs – weather, indoor temperature setpoints, HVAC system component capabilities, cost of energy etc. Setting an optimization parameter, perhaps lowest possible energy use, or lowest possible energy cost, the system then constructs the optimal control sequence for that HVAC system for the immediate future. A new control sequence is optimized and uploaded via the internet to the building every 5 minutes. In the BrightBox initial commercial deployments, 20%-30% HVAC energy savings have been typical with this approach.

### 5.3.2 Components of the system

The components of the system include an engineering team in Berkeley, CA that quickly builds a model of the parts and pieces and interactions of the HVAC system in a specific building, algorithms that produce optimized control sequences for that HVAC system that live in servers in the cloud, and then access and updates to the HVAC system in a specific building via an ALC WebCTRL interface.

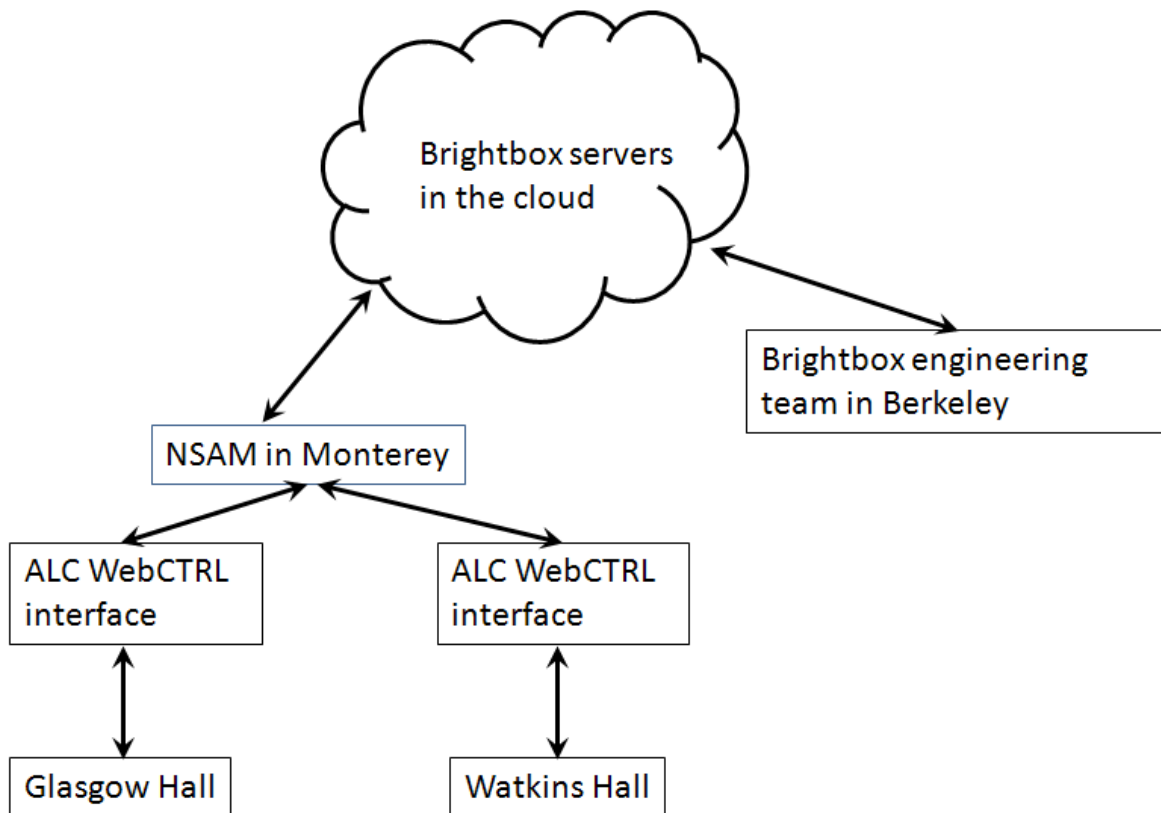


Figure 12. System design

### **5.3.3 System Integration**

The existing HVAC systems in Glasgow Hall and Watkins Hall are not optimized for the lowest energy consumption or cost performance. BrightBox will demonstrate better HVAC system performance.

The existing ALC controls had older versions of the operating system software and have been upgraded to the latest version. However, no hardware changes will be required. Rather, BrightBox will update the HVAC system control sequences with optimized versions remotely over the internet every 5 minutes.

### **5.3.4 System Controls**

BrightBox does have an “off” button. If at any time, an onsite facilities manager believes that the BrightBox HVAC optimization software isn’t working properly, there is a big “off” button available so that person can turn the BrightBox optimization software off. This button is available in the ALC WebCTRL interface.

## **5.4 OPERATIONAL TESTING**

### **5.4.1 Operational Testing of Cost and Performance**

Operational testing of cost and performance is ongoing and continuous. Once the BrightBox models of the HVAC systems are built and operational they operate continuously unless turned off.

### **5.4.2 Modeling and Simulation**

The BrightBox model-predictive control solution is central and critical to the success of the project. Below is a task list showing the work breakdown for extending the BrightBox BOMP model to HVAC systems including built-up chiller plants and air-handling units.

#### **Task**

1. Build Chiller Schema
  - a. Develop chiller model
  - b. Develop pump model
  - c. Develop load model
  - d. Assemble chiller plant model
  - e. Develop coil model to decouple water and air systems
2. Build Air-side schema
  - a. Develop AHU model
  - b. Assemble air-side model
3. Build Identification Routines
  - a. Chiller plant

- b. Air-side
  - c. Load aggregator
- 4. Chiller Control Architecture
  - a. Control variables definition and sampling time
  - b. Interaction with the air side
- 5. TOPP Model Simulation
  - a. Run optimization of MPC problem with  $H_p=2$  as simulator
  - b. Get simulation results from trend sets
- 6. Finite State Machine Design and Integration (AutoCx infrastructure)
  - a. Requirement review
  - b. Choose packages or libraries
  - c. Develop modularized approach
- 7. TOPP Model Optimization
  - a. Enumerate all possible feasible combinations of logic variables
  - b. Dispatch TOPP workers to simulate system
  - c. Reduce the set of simulation results to a single optimum
- 8. Extend to real-time implementation
  - a. review operational constraints
- 9. System Monitoring
  - a. Chiller running status
  - b. Chiller plant savings visualization
  - c. AHU running status
- 10. User Interface Design and Implementation
  - a. Chiller plant configuration pages
  - b. TOPP model optimization pages
  - c. Chiller plant monitoring pages
  - d. AHU monitoring pages
  - e. Chiller plant reporting page

### 5.4.3 Timeline

Below is a list of milestones and the expected month and year of completion.



**Table 2. Milestones and Date of Completion**

<b>Milestone</b>	<b>Completion (Month/Year)</b>
Confirm demonstration site	07/2014
Kickoff Call	07/2014
Project Plan Approved	07/2014
Submit Draft Execution Plan for Year 1 Funding Increment	07/2014
Submit Draft Table 1 Performance Objectives and Test Design	07/2014
Submit Draft Submit Draft Demonstration Plan	09/2014
Baseline performance	11/2014
Initiate requests for Permits, Approvals, Agreements	11/2014
Required Permits, Approvals and/or Agreements received/completed	12/2014
Demonstration Preparation/Mobilization	01/2015
Complete Software Development Part 1	02/2015
First IPR	02/2015
Initiate Demonstration	03/2015
Complete Software Development Part 2	06/2015
Demonstration 25% complete	06/2015
Submit Draft Execution Plan for Year 2 Increment	09/2015
Demonstration 50% complete	10/2015
Demonstration 75% complete	01/2016
Submit Draft Outbrief	02/2016
Second IPR	02/2016
Collect Data	03/2016
Conduct Data Analysis	06/2016
Decommissioning	06/2016
Submit Draft Final Report	06/2016
Property Transfer	07/2016
Submit Final Final Report	07/2016
Submit Draft C&P Report	07/2016
Demonstration Complete	07/2016

## 5.5 SAMPLING PROTOCOL

**Table 3. Sampling Protocol**

<b>Item</b>	<b>Data</b>
Data collector	BrightBox Technologies remotely over the internet
Data Recording	BrightBox Technologies remotely over the internet. If the network goes down, any trend data that is required for the operation of the control system is cached locally and can be recovered. Any additional data that BrightBox Technologies might be collecting in realtime would be lost for the period of the network outage.
Data description	Power and energy consumption, supply and return air and water temperatures, flow rates, thermostat values, and fan speeds etc. Minimum sampling rate of 5 minutes.
Data storage and backup	BrightBox utilizes cloud services so data backup is continuous and automatic.
Data collection diagram	The data collection for this project is very complex. A diagram would not be practical or useful.
Non-standard data	No non-standard data will be collected
Survey Questionnaires	A user satisfaction survey will be part of this project

## **5.6 EQUIPMENT CALIBRATION AND DATA QUALITY ISSUES**

### **5.6.1 Equipment Calibration**

Where equipment calibration is required, subcontractor Sunbelt controls will perform the calibration. We do not anticipate calibration will be required; however, based on the system design and operation, we establish a reasonable range for each parameter. We monitor the parameter continuously relative to the reasonable range so we can quickly identify equipment that may require calibration.

### **5.6.2 Quality Assurance Sampling**

We have found that our data collection through the ALC controls infrastructure is very reliable.

### **5.6.3 Post-Processing statistical analysis**

Real time statistical analysis of energy savings is built in to the BrightBox software optimization platform. Incorrect readings or faulty measurement equipment will be easy to identify.

## **6.0 PERFORMANCE ASSESSMENT**

### **6.1 PERFORMANCE OBJECTIVE ANALYSIS OVERVIEW**

ESTCP project EW-201409 aimed at demonstrating the benefits of innovative software technology for building HVAC systems. These benefits included reduced system energy use and cost as well as improved performance driven by autonomous commissioning and optimized system control. In the end, while many individual elements of the project were completed successfully, the project as a whole was not able to successfully demonstrate the technology.

The following items were successfully completed as part of this demonstration project.

- Technology development related to incorporating chilled-water plant elements into the BrightBox system
- Air-cooled chiller plant models
- Chilled-water (and condenser water) pump models
- Cooling tower models (for the sake of validation against the Taylor Engineering software)
- Primary-only variable-flow chilled-water system operation (for validation)
- Building controls system expansion to include new sensors, meters, and graphic screens at Glasgow and Watkins
- Establishment of secure bi-directional data connection between BrightBox remote secure data-center and the NSAM WebCTRL system.
- Deployment of AutoCx at Watkins Hall.

The following items were not successfully demonstrated.

- Testing of ‘air-side’ BrightBox system components
- Operation of the BrightBox chilled-water-system controls optimization.

The two buildings at the Naval Support Activity Monterey (NSAM) facility that were selected for this demonstration met the following criteria.

- Employed an Automated Logic Controls (ALC) building control system
- Contained HVAC central plants containing multiple chillers with the correct type of control points available and integrated into the ALC system
- Employed ‘variable air volume reheat’ (VAV-reheat) HVAC distribution systems
- Contained existing energy and flow meters to enable monitoring and verification

The first building selected was Building 245 (Watkins Hall). In the end we were not able to deploy the advanced control solution to this building because of chiller equipment failure. The Watkins plant consisted of three chillers, CH-1, CH-2, and CH-3. Despite being co-located, CH-1 served Building 246 next door, which contains critical security program spaces.

During this project CH-1 became permanently disabled and CH-2 was repurposed to serve Building 246. This left only CH-3 to serve the subject Building 245, making the deployment infeasible.

The second building selected was Building 305 (Glasgow Hall). At this building we were not able to deploy the advanced control software because the chilled-water supply temperature setpoint control point was not properly configured at any of the three chillers serving this building. This control point is a key element in deploying the optimal control solution and it was not available.

At Glasgow, NSAM staff, NSAM service contractors, and BrightBox staff were eventually able to diagnose the cause of the malfunctioning control point and we did identify measures to repair the equipment. The ESTCP program agreed to make extra funds available to fix the equipment, but another project roadblock appeared. BrightBox Technologies went out of business at this time due to slow market adoption of our software.

Anecdotal evidence, academic studies, and system simulations clearly demonstrate the importance and capacity for best-in-class control solutions to improve system performance and reduce energy use and cost. However, implementing these solutions into the extremely heterogeneous and often malfunctioning or misconfigured HVAC systems in real operating buildings poses a major challenge to reaping the benefits promised by advanced control. For these reasons, BrightBox Technologies refocused our efforts away from optimal control toward autonomous commissioning with the goal of establishing a correctly-configured and properly-operating foundation onto which optimal control could eventually be deployed. Unfortunately, we were not yet able to successfully develop a market for autonomous commissioning products despite the clear need and benefits. BrightBox Technologies ceased operations in this market at the end of March 2016.

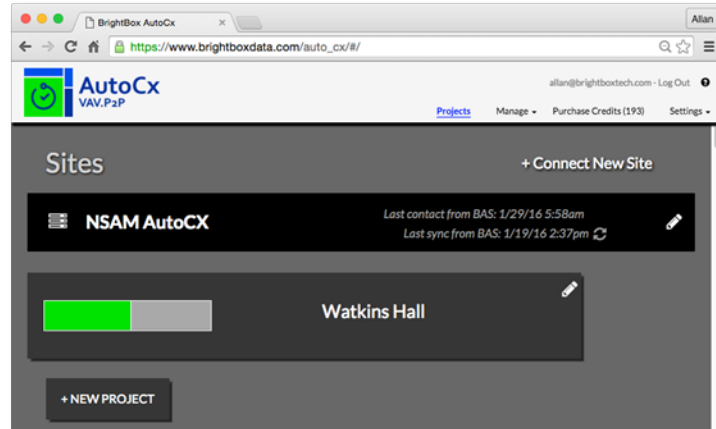
## **6.2 STATISTICAL METHODOLOGIES**

We had originally planned to use comparisons of energy use with the BrightBox software optimization program either on or off integrated over time to show energy savings. We were never able to deploy the software, so we were not able to perform this statistical analysis for the deployment at NSAM.

## **6.3 GRAPHICAL METHODOLOGIES**

We had originally planned to use visual comparisons of energy use with the BrightBox software optimization program either on or off, integrated over time to show energy savings. As described in section 6.2 above, the optimization software was not deployed so there are no graphic analyses of the data to present.

We were able to partially deploy the “AutoCx” autonomous commissioning software in Watkins hall where some VAVR zone equipment was installed. The images below show the Watkins Hall AutoCx software results.



**Figure 13. AutoCx User Interface**

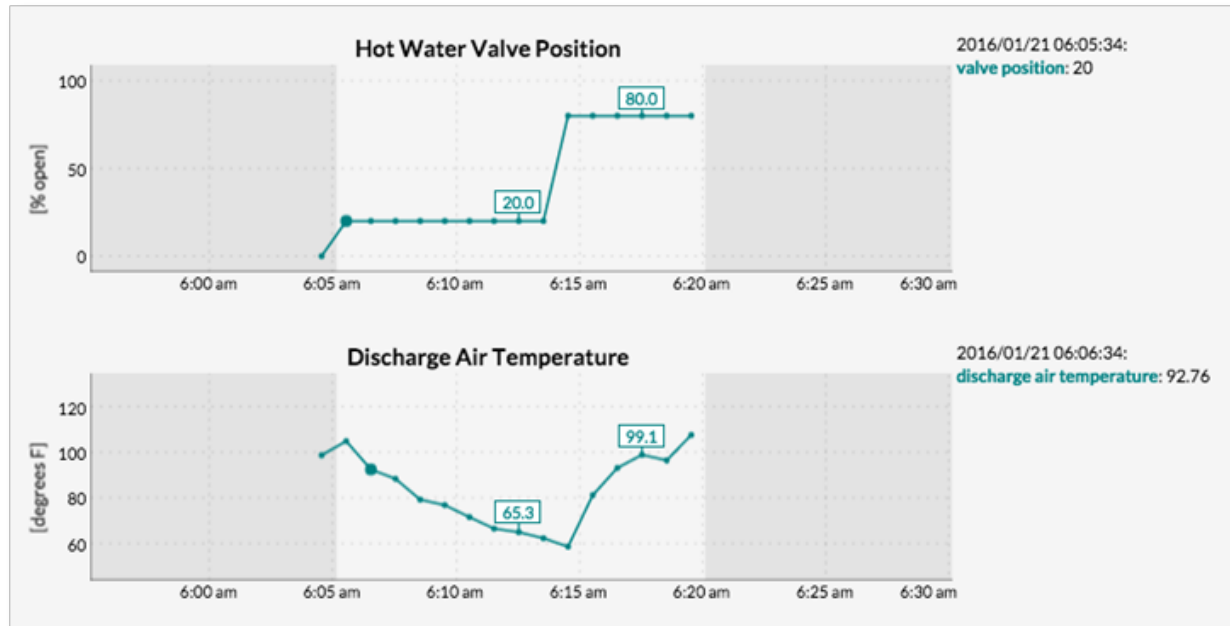
This image shows a screen capture of the AutoCx web-application with the NSAM Watkins Hall project indicated. The green progress bar indicates that roughly half of the available tests were able to be performed at Watkins Hall.

The screenshot shows the 'Watkins Hall NSAM AutoCx' results page. It displays a table of test results for 'Fan Coil Type-F (2-pipe HW recirc)' and 'b245\_vav\_hw\_rht-(1)'. The table includes columns for STPT, DAT, ZAT, AF-C, DP-C, HWV, and COOL. A timeline at the bottom shows dates from Wed 1/20/16 to Thu 1/21/16.

	STPT	DAT	ZAT	AF-C	DP-C	HWV	COOL
VAV 1-1-1	✓	✓	✓	✓	✓	✓	✓
VAV 1-1-2	✓	✓	✓	✓	✓	✓	✓
VAV 1-1-3	✓	✓	✓	✓	✓	✓	✓
VAV 1-1-4	✓	✓	✓	✓	✓	✓	✓
VAV 1-1-5	✓	✓	✓	✓	✓	✓	✓
VAV 1-1-6	✓	✓	✓	✓	✓	✓	✓
VAV 1-2-1	✓	✓	✓	✓	✓	✓	✓
VAV 1-2-2	✓	✓	✓	✓	✓	✓	✓
VAV 1-2-3	✓	✓	✓	✓	✓	✓	✓
VAV 1-2-4	✓	✓	✓	✓	✓	✓	✓
VAV 1-2-5	✓	✓	✓	✓	✓	✓	✓
VAV 3-1-1	✓	✓	✓	✓	✓	✓	✓
VAV 3-1-2	✓	✓	✓	✓	✓	✓	✓
VAV 3-1-3	✓	✓	✓	✓	✓	✓	✓
VAV 3-1-4	✓	✓	✓	✓	✓	✓	✓
VAV 3-1-5	✓	✓	✓	✓	✓	✓	✓
VAV 3-1-6	✓	✓	✓	✓	✓	✓	✓
VAV 3-1-7	✓	✓	✓	✓	✓	✓	✓
VAV 3-1-8	✓	✓	✓	✓	✓	✓	✓

**Figure 14. AutoCx User Interface**

The figure above shows the ‘test results’ view of the Watkins Hall AutoCx deployment. Green checkmarks indicate that tests were run and passed. Gray boxes indicate that tests were not run. In most cases tests were not run because they would have affected space conditions (heating up or cooling down the space) and it was known that these spaces contained laboratory program and users would need to be notified about the performance of the tests. This coordination did not occur before work on the project ceased.

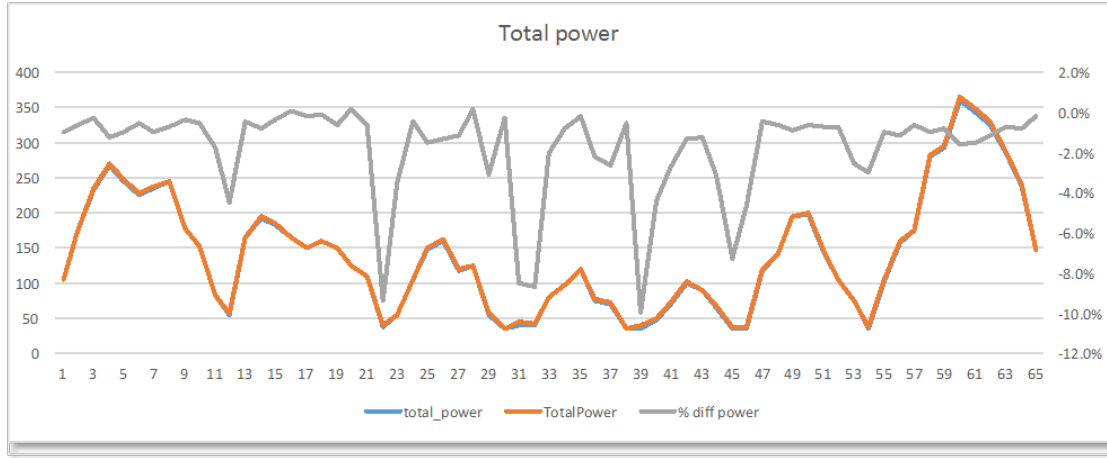


**Figure 15. AutoCx Results View**

This figure shows how data signals are used to assess correct operation. Systems are actively manipulated by the BrightBox AutoCx software as can be seen in the top graph – the hot water valve is driven to 20% open then to 80% open, then returned to automatic operation. The lower graph shows that the discharge air temperature increased, indicating that the hot water valve is operating correctly.

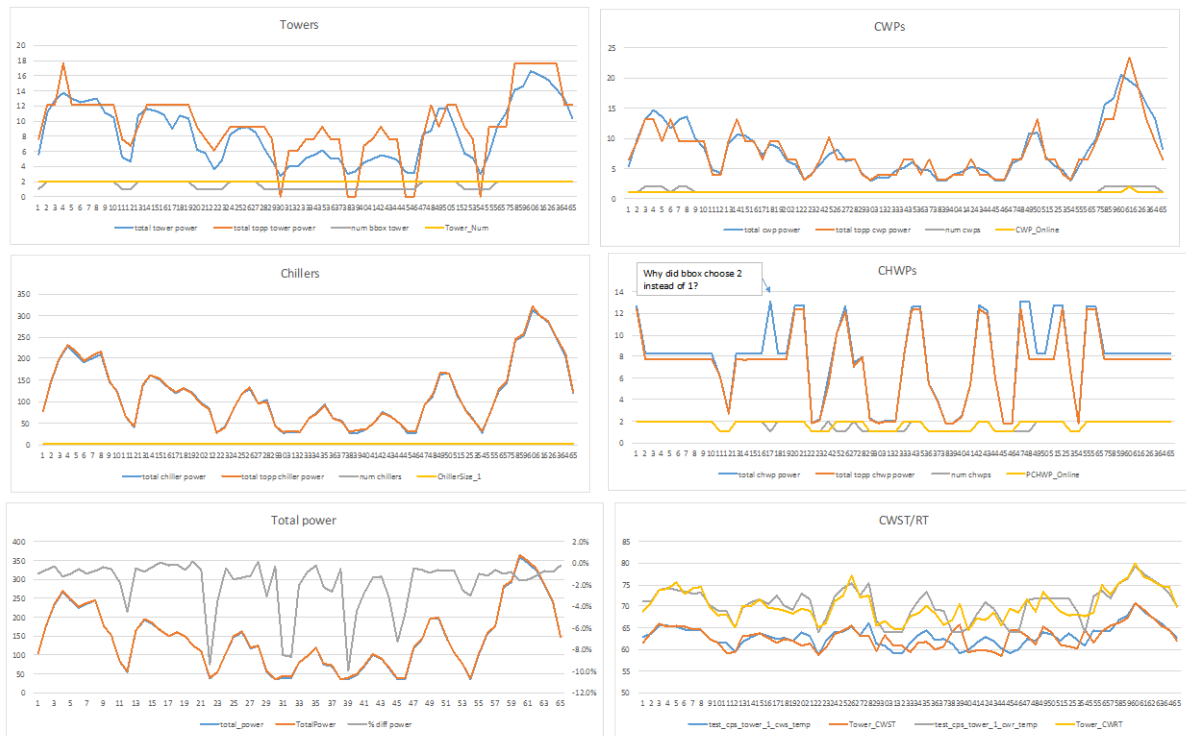
## 6.4 MODELING AND SIMULATION

We used the TOPP model (Theoretical Optimum Plant Performance model) to establish the theoretical optimum and calculate plant power demands. We modeled the same plant in the BrightBox simulation and optimal control platform to validate the BrightBox software performance against a well-known and validated source. The graphic below show TOPP results compared to BrightBox results – a very good match is indicated.



**Figure 16. Modeling Comparison Detail**

This figure show TOPP total power predictions in orange and BrightBox total power predictions in blue for an example chilled-water plant. The two match up well and in all cases the BrightBox optimal control approach results in slightly lower power use. The gray line shows a percentage difference between the TOPP results and the BrightBox results and values are read on the right-hand Y-axis scale. Please note that the wide variation in percent difference is due to the significant variation in the magnitude of the power use values. When the magnitude of the power-use is small, then even small differences between the TOPP values and the BrightBox values end up looking like large percentage differences.



**Figure 17. Modeling Comparison Overview**

This figure shows simulated optimal control key variables such as cooling tower power, chiller power, condenser water pump power, chilled water power, and condenser water supply and return temperature. It is interesting to see that the TOPP methodology and the BrightBox methodology determine similar-but-different control approaches, resulting in slightly lower power use in the BrightBox simulated case.

## **6.5 SENSITIVITY ANALYSIS**

Not applicable.

## **6.6 ANECDOTAL PERSPECTIVES**

Although the BrightBox team is coordinating with leadership including the Public Works Officer in charge (LCDR Oscar Antillion), NSAM representative Doug Taber, our primary technical work will be with Facilities Manager Michael Fitzgerald and HVAC technician Erik Abbot. We propose to have a formal exit interview with Michael and Erik at the end of the project. We will administer the survey (Appendix C) and ask for any additional comments or ways we could have improved the project.

## **6.7 INDUSTRY STANDARDS**

ASHRAE has formed a committee to develop standard control sequences for HVAC systems but this effort is in its' infancy. There are no industry standards for model-based predictive control systems applied to HVAC equipment that we are aware of.

## **6.8 INTERNAL VALIDITY**

No internal validity tests are planned at this time.

## **6.9 EXTERNAL VALIDITY**

Not applicable



## 7.0 COST ASSESSMENT

The BrightBox solution is more similar to the ESSCO model than a traditional life-cycle cost model. The BrightBox technology costs a customer nothing up front. Once the BrightBox technology has been installed and proven, BrightBox retains a portion of the cost savings.

A typical contract would be issued and renewed on an annual basis. If an on-site server had to be installed because of security concerns, responsibility for upfront and maintenance costs would fall to the customer.

After this project is over, NSAM will be offered a contract to continue the BrightBox service. No setup fee will be charged. However, for the purposes of performing the economic analysis, we will assume a \$10,000 setup fee.

BrightBox target cost numbers assume typical baseline HVAC energy cost is \$2 per square foot per year. Assuming BrightBox can save 10% of HVAC energy costs on average, that would be \$0.2 per square foot per year. A setup fee of \$10,000 per project, \$1,000 for operator training, and split of 75% of the savings to BrightBox and 25% to NSAM. The total square footage for Glasgow and Watkins hall is roughly 225,000. This implies annual energy costs of \$450,000 and associated savings of \$45,000. NSAM keeps \$11,250 for a simple payback time of just under one year.

- Building Life-Cycle Cost Program:

The data from Table 4 along with the assumptions above, a 3% discount rate, and a 10 year lifetime were entered into BLCC5 for analysis. The detailed life-cycle cost report is attached as Appendix F. In summary, over a ten-year lifetime, the base case total life-cycle cost is \$4,748,295 or \$513,263 per year. The alternate BrightBox case total life-cycle cost is \$4,036,210 or \$436,291 per year.

- Life-Cycle Cost Table: See Table 4

- Life-Cycle Cost Elements:

The main cost to achieve the savings is the \$10,000 installation cost.

- Life-Cycle Cost Timeframe:

The timeframe for the life-cycle cost estimate is the DOE default of 10 years. While the software itself doesn't wear out per se, it is anticipated that after a 10 year lifetime, a better solution may be available.

**Table 4. Cost Model**

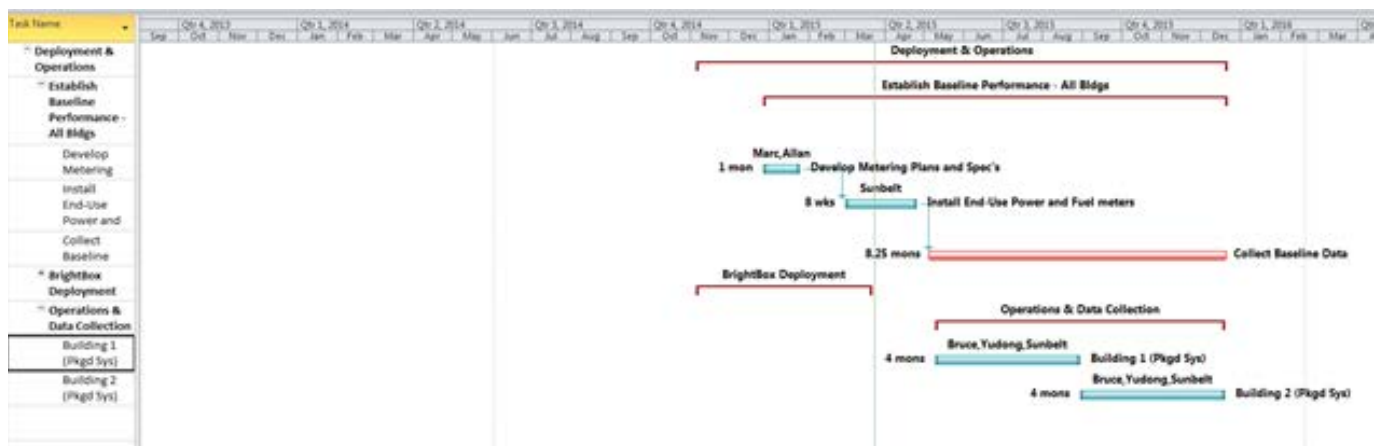
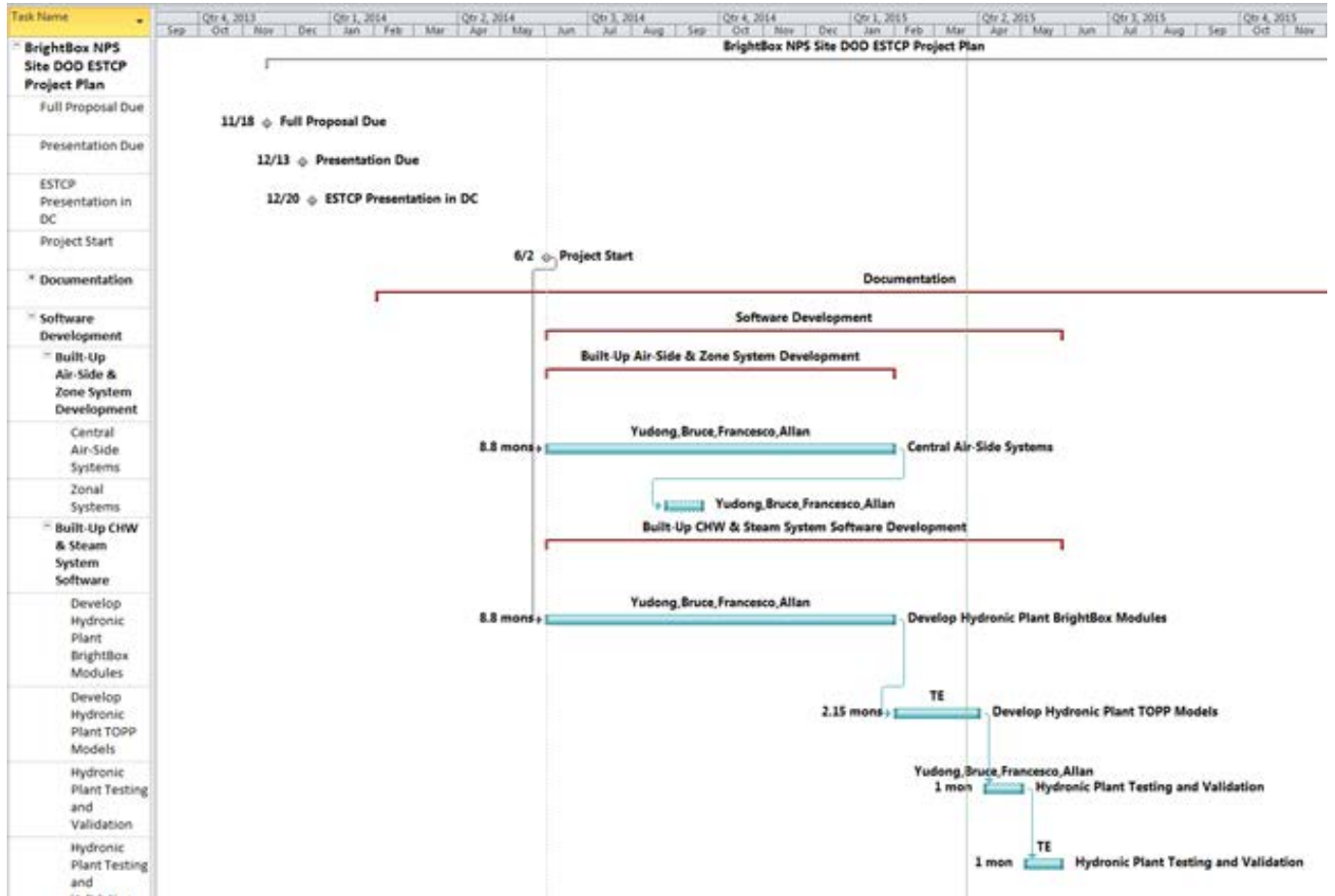
<b>Cost Element</b>	<b>Data Tracked During the Demonstration</b>
<b>Hardware capital costs</b>	\$0
<b>Installation costs</b>	\$10,000
<b>Consumables</b>	\$0
<b>Facility operational costs</b>	10% reduction in HVAC energy costs used for this plan, actual energy reduction will be used for final report
<b>Maintenance</b>	\$0.10 per square foot per year. For Watkins and Glasgow Halls at 226,111 square feet this is \$22,611 per year.
<b>Hardware lifetime</b>	10 years
<b>Operator training</b>	Included in maintenance fee
<b>Salvage Value</b>	\$0

## **8.0 TECHNOLOGY TRANSFER**

Due to the unsuccessful nature of this demonstration project, no technology transfer activities are planned. This final report serves as the documentation of the project successes and failures. In fact BrightBox as a company has completely ceased operations in this market due in part to wider-market barriers that we encountered that were similar to those we found at NSAM.

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## 9.0 SCHEDULE OF ACTIVITIES

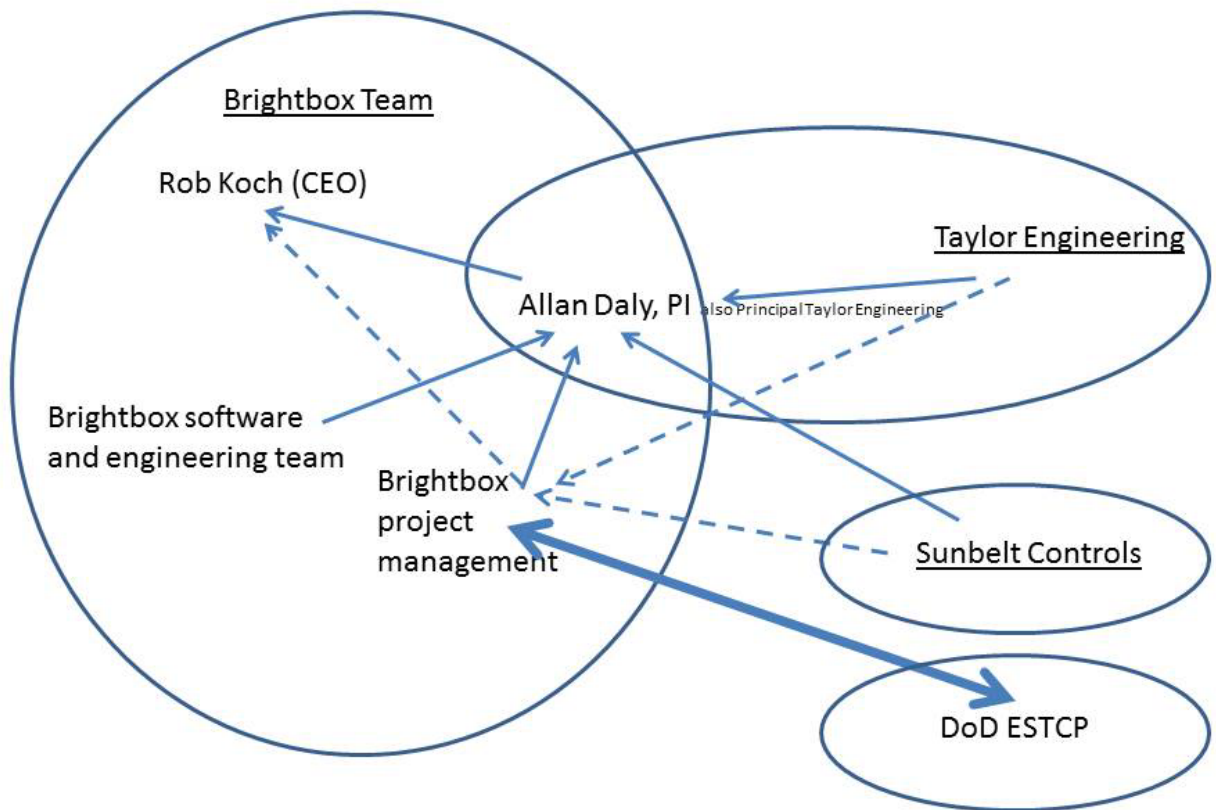


Note that the two sections of the Gantt chart are offset.

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## 10.0 MANAGEMENT AND STAFFING

Allan Daly, the BrightBox Principal Investigator managed the software development and engineering effort on a day-to-day basis. Marc Fountain managed all coordination, planning, reporting, communication, invoicing etc., with the DoD. Mark Hydeman led the Taylor Engineering sub-contractor effort and Rich Phifer the Sunbelt Controls sub-contractor effort. However, Allan was also a principal at Taylor Engineering and worked with Mark to coordinate and execute the Taylor Engineering scope of work.



**Figure 18. Management and Staffing**

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## **APPENDIX A   HEALTH AND SAFETY PLAN (HASP)**

BrightBox is a software solution that should not have any physical health and safety impacts. We will not be engaging in construction or any activities that could impact Health and Safety. Therefore, a Health and Safety Plan is not included.

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## APPENDIX B POINTS OF CONTACT

Point of Contact Name	Organization Name Address	Phone Email	Role in Project
Allan Daly	BrightBox Technologies	510-220-0500 allan@brightboxtech.com	Principal Investigator
Rob Koch	BrightBox Technologies	650-743-2082 rob@brightboxtech.com	Chief Executive Officer
Marc Fountain	BrightBox Technologies	510-681-4778 marc@brightboxtech.com	Project Manager
Mark Hydeman	Taylor Engineering	(510) 263-1543 mhydeman@taylor-engineering.com	Sub-contractor lead
Rich Phifer	Sunbelt Controls	650-333-8685 rphifer@sunbeltcontrols.com	Sub-contractor lead
LCDR Oscar Antillon	NSAM	oscar.antillon@navy.mil	Public Works Officer (lead for NSAM)
Matt Seuss	NSAM	matthew.suess@navy.mil	Deputy Public Works Officer
Michael Fitzgerald	NSAM		Facilities Manager
Erik Abbot	NSAM	erik.abbott@navy.mil	HVAC technician
Douglass Taber, RA, CEM	NSAM	831-656-3653 douglass.c.taber@navy.mil	Demonstration site representative

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## APPENDIX C SAMPLE SURVEY

Dear NSAM Facilities Management Staff:

BrightBox Technologies has now completed our ESTCP demonstration project at your facility. As part of our agreement with the Department of Defense, we are required to ask for your feedback to help evaluate the success of the project. Please take a moment to complete the brief survey below and return to Marc Fountain, BrightBox Technologies 2040 Bancroft Way Suite 302, Berkeley, CA 94704 or [marcfountain@comcast.net](mailto:marcfountain@comcast.net)

**1) Did you find the BrightBox software easy to work with?**

1	2	3	4	5
Difficult	Somewhat difficult	Neither difficult nor easy	Somewhat easy	Extremely easy

**2) Did any issues come up with the software that were difficult to resolve?**

1	2	3	4	5
Difficult	Somewhat difficult	Neither difficult nor easy	Somewhat easy	Extremely easy

(please elaborate)

**3) Were the promised energy savings realized or exceeded?**

1	2	3	4	5
Not realized	Somewhat realized	Realized	Somewhat exceeded	Extremely exceeded

**4) Were the promised cost savings realized or exceeded?**

1	2	3	4	5
Not realized	Somewhat realized	Realized	Somewhat exceeded	Extremely exceeded

5) Would you recommend BrightBox to a colleague?

1	2	3	4	5
Definitely not	Probably not	Undecided	Probably	Definitely

6) Any other comments for the BrightBox team?

Thank you for your feedback!



## **APPENDIX D   NSAM/NPS CHILLED WATER PLANT METERING PLAN**

The goal of the attached metering plan is to provide adequate data to be able to characterize and validate the performance of the following BrightBox model components that will be deployed at this site. All meters will be connected to the existing WebCTRL building controls system and will remain in place after the project is complete.

- Chillers
- Cooling Towers
- Pumps
- Coils (CHW)

The metering plan is a comprehensive list of all the metering points.

### **NSAM/NPS BRIGHTBOX PROJECT -- METER INSTALLATION PLAN**

#### **Watkins Hall (Building 245)**

- CH-1 (air cooled)
  - Power meter (Veris, Modbus)
- CH-2 (air cooled)
  - Power meter (Veris, Modbus)
- CH-3 (air cooled)
  - Power meter (Veris, Modbus)
  - Evaporator dp sensor
- P-3 (CHW pump)
  - Inlet/outlet dp sensor
- P-4 (CHW pump)
  - Inlet/outlet dp sensor
- P-5 (CHW pump)
  - Inlet/outlet dp sensor
- FC-2-E
  - CHW coil dp sensor
  - CHWS temperature sensor
  - CHWR temperature sensor
- AH-3-2
  - CHW coil dp sensor
  - CHWS temperature sensor

- CHWR temperature sensor

#### Glasgow Hall (Building 305)

- CH-1 (air cooled)
  - Power meter (Veris, Modbus)
  - Evaporator dp sensor
- CH-2 (air cooled)
  - Power meter (Veris, Modbus)
  - Evaporator dp sensor
- CH-3 (air cooled)
  - Power meter (Veris, Modbus)
  - Evaporator dp sensor
- CHWP-1 (CHW pump)
  - Power meter (Veris, Modbus)
  - Inlet/outlet dp sensor
- CHWP-2 (CHW pump)
  - Power meter (Veris, Modbus)
  - Inlet/outlet dp sensor
- FC-B-06
  - CHW coil dp sensor
  - CHWS temperature sensor
  - CHWR temperature sensor
- FC-B-09
  - CHW coil dp sensor
  - CHWS temperature sensor
  - CHWR temperature sensor
- FC-1-03
  - CHW coil dp sensor
  - CHWS temperature sensor
  - CHWR temperature sensor

## **APPENDIX E DOCUMENTATION SUPPORTING REDUCING THE NUMBER OF BUILDINGS IN THE DEMONSTRATION TO TWO.**

**Winter 2015 ESTCP In-Progress Review Project Number: EW-201409**

**Principal Investigator: Mr. Allan Daly (BrightBox Technologies)**

**Project Title: Rapid Deployment of Optimal Control for Building**

**HVAC Systems using Innovative Software Tools and a Hybrid Heuristic/Model-Based Control Approach**

### **Action Items**

1. In your next Quarterly Progress Report (QPR) due **15 April 2015**, briefly discuss the feasibility of hosting DoD domains through Amazon Web Services for future application of the BrightBox technology. Determine if DoD accredits the Amazon Web Services for Industrial Control System applications.

2. In the Final Report discuss the potential impact of time of use (TOU) pricing on the long term application of the technology.

### **Comments**

1. Limiting the demonstration to two buildings with high fidelity metering is acceptable to ESTCP.

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## APPENDIX F BLCC5 LIFE CYCLE COST ANALYSIS

### 12.0 NIST BLCC 5.3-13: DETAILED LCC ANALYSIS

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A

#### 12.1 GENERAL INFORMATION

<b>File Name:</b>	C:\Program Files\BLCC5\projects\NSAM.xml
<b>Date of Study:</b>	Tue Apr 14 11:12:41 PDT 2015
<b>Analysis Type:</b>	FEMP Analysis, Energy Project
<b>Project Name:</b>	NSAM
<b>Project Location:</b>	California
<b>Analyst:</b>	Marc
<b>Base Date:</b>	January 1, 2015
<b>Service Date:</b>	January 1, 2016
<b>Study Period:</b>	11 years 0 months (January 1, 2015 through December 31, 2025)
<b>Discount Rate:</b>	3%
<b>Discounting Convention:</b>	End-of-Year

Discount and Escalation Rates are REAL (exclusive of general inflation)

### 13.0 ALTERNATIVE: BASE CASE

#### 13.1 INITIAL COST DATA (NOT DISCOUNTED)

##### 13.1.1 Initial Capital Costs

*13.1.1.1.1 (adjusted for price escalation)*

**Initial Capital Costs for All Components: \$0**

##### 13.1.1.2 Component:

*13.1.1.2.1. Cost-Phasing*

<b>Date</b>	<b>Portion</b>	<b>Yearly Cost</b>
<b>January 1, 2015</b>	100%	\$0
-----	-----	-----

**Total (for Component)** \$0

### 13.1.2. Energy Costs: Electricity

*13.1.2.1.1 (base-year dollars)*

<b>Average</b>	<b>Average</b>	<b>Average</b>	<b>Average</b>
<b>Annual Usage</b>	<b>Price/Unit</b>	<b>Annual Cost</b>	<b>Annual Rebate</b>
5,625,000.0 kWh	\$0.08000	\$450,000	\$0

## 13.2 LIFE-CYCLE COST ANALYSIS

	<b>Present Value</b>	<b>Annual Value</b>
<b>Initial Capital Costs</b>	\$0	\$0
<b>Energy Costs</b>		
<b>Energy Consumption Costs</b>	\$3,748,654	\$405,208
<b>Energy Demand Charges</b>	\$999,641	\$108,055
<b>Energy Utility Rebates</b>	\$0	\$0
	-----	-----
<b>Subtotal (for Energy):</b>	\$4,748,295	\$513,263
<b>Water Usage Costs</b>	\$0	\$0
<b>Water Disposal Costs</b>	\$0	\$0
<b>Operating, Maintenance &amp; Repair Costs</b>		
<b>Component:</b>		
<b>Annually Recurring Costs</b>	\$0	\$0
<b>Non-Annually Recurring Costs</b>	\$0	\$0
	-----	-----
<b>Subtotal (for OM&amp;R):</b>	\$0	\$0
<b>Replacements to Capital Components</b>		
<b>Component:</b>	\$0	\$0
	-----	-----
<b>Subtotal (for Replacements):</b>	\$0	\$0
<b>Residual Value of Original Capital Components</b>		
<b>Component:</b>	\$0	\$0

	-----	-----
<b>Subtotal (for Residual Value):</b>	\$0	\$0
<b>Residual Value of Capital Replacements</b>		
<b>Component:</b>	\$0	\$0
	-----	-----
<b>Subtotal (for Residual Value):</b>	\$0	\$0
<b>Total Life-Cycle Cost</b>	\$4,748,295	\$513,263

### 13.2.1 Emissions Summary

<b>Energy Name</b>	<b>Annual</b>	<b>Life-Cycle</b>
<b>Electricity:</b>		
<b>CO2</b>	1,479,019.47 kg	14,788,170.00 kg
<b>SO2</b>	364.55 kg	3,645.00 kg
<b>NOx</b>	607.58 kg	6,075.00 kg
<b>Total:</b>		
<b>CO2</b>	1,479,019.47 kg	14,788,170.00 kg
<b>SO2</b>	364.55 kg	3,645.00 kg
<b>NOx</b>	607.58 kg	6,075.00 kg

## 14.0 ALTERNATIVE: BRIGHTBOX

### 14.1 INITIAL COST DATA (NOT DISCOUNTED)

#### 14.1.1 Initial Capital Costs

*14.1.1.1.1 (adjusted for price escalation)*

**Initial Capital Costs for All Components: \$10,000**

#### 14.1.1.2 Component:

*14.1.1.2.1 Cost-Phasing*

<b>Date</b>	<b>Portion</b>	<b>Yearly Cost</b>
<b>January 1, 2015</b>	100%	\$10,000
	-----	-----

<b>Total (for Component)</b>	<b>\$10,000</b>
------------------------------	-----------------

## 14.1.2 Energy Costs: Electricity

14.1.2.1.1 (base-year dollars)

<b>Average Annual Usage</b>	<b>Average Price/Unit</b>	<b>Average Annual Cost</b>	<b>Average Annual Demand</b>	<b>Average Annual Rebate</b>
5,062,500.0 kWh	\$0.08000	\$405,000	\$60,000	\$0

## 14.2 LIFE-CYCLE COST ANALYSIS

	<b>Present Value</b>	<b>Annual Value</b>
<b>Initial Capital Costs</b>	\$10,000	\$1,081
<b>Energy Costs</b>		
<b>Energy Consumption Costs</b>	\$3,343,591	\$361,423
<b>Energy Demand Charges</b>	\$495,347	\$53,544
<b>Energy Utility Rebates</b>	\$0	\$0
	-----	-----
<b>Subtotal (for Energy):</b>	\$3,838,938	\$414,967
<b>Water Usage Costs</b>	\$0	\$0
<b>Water Disposal Costs</b>	\$0	\$0
<b>Operating, Maintenance &amp; Repair Costs</b>		
<b>Component:</b>		
<b>Annually Recurring Costs</b>	\$187,272	\$20,243
<b>Non-Annually Recurring Costs</b>	\$0	\$0
	-----	-----
<b>Subtotal (for OM&amp;R):</b>	\$187,272	\$20,243
<b>Replacements to Capital Components</b>		
<b>Component:</b>	\$0	\$0
	-----	-----
<b>Subtotal (for Replacements):</b>	\$0	\$0
<b>Residual Value of Original Capital Components</b>		



<b>Component:</b>	\$0	\$0
	-----	-----
<b>Subtotal (for Residual Value):</b>	\$0	\$0
<b>Residual Value of Capital Replacements</b>		
<b>Component:</b>	\$0	\$0
	-----	-----
<b>Subtotal (for Residual Value):</b>	\$0	\$0
<b>Total Life-Cycle Cost</b>	\$4,036,210	\$436,291

#### 14.2.1 Emissions Summary

<b>Energy Name</b>	<b>Annual</b>	<b>Life-Cycle</b>
<b>Electricity:</b>		
<b>CO2</b>	1,331,117.52 kg	13,309,353.00 kg
<b>SO2</b>	328.09 kg	3,280.50 kg
<b>NOx</b>	546.82 kg	5,467.50 kg
<b>Total:</b>		
<b>CO2</b>	1,331,117.52 kg	13,309,353.00 kg
<b>SO2</b>	328.09 kg	3,280.50 kg
<b>NOx</b>	546.82 kg	5,467.50 kg

## NSAM / NSP Chilled Water Plant Metering Plan

1. **Identify the problem.** The first step is to identify the problem. This involves understanding the symptoms and the context in which they are occurring.

Building		Watsons (R145)										Imperial (R334)										Glasgow (R395)																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																									
Category	Tag	UoL1	UoL2	UoL3	UoL4	UoL5	UoL6	UoL7	UoL8	UoL9	UoL10	UoL11	UoL12	UoL13	UoL14	UoL15	UoL16	UoL17	UoL18	UoL19	UoL20	UoL21	UoL22	UoL23	UoL24	UoL25	UoL26	UoL27	UoL28	UoL29	UoL30	UoL31	UoL32	UoL33	UoL34	UoL35	UoL36	UoL37	UoL38	UoL39	UoL40	UoL41	UoL42	UoL43	UoL44	UoL45	UoL46	UoL47	UoL48	UoL49	UoL50	UoL51	UoL52	UoL53	UoL54	UoL55	UoL56	UoL57	UoL58	UoL59	UoL60	UoL61	UoL62	UoL63	UoL64	UoL65	UoL66	UoL67	UoL68	UoL69	UoL70	UoL71	UoL72	UoL73	UoL74	UoL75	UoL76	UoL77	UoL78	UoL79	UoL80	UoL81	UoL82	UoL83	UoL84	UoL85	UoL86	UoL87	UoL88	UoL89	UoL90	UoL91	UoL92	UoL93	UoL94	UoL95	UoL96	UoL97	UoL98	UoL99	UoL100	UoL101	UoL102	UoL103	UoL104	UoL105	UoL106	UoL107	UoL108	UoL109	UoL110	UoL111	UoL112	UoL113	UoL114	UoL115	UoL116	UoL117	UoL118	UoL119	UoL120	UoL121	UoL122	UoL123	UoL124	UoL125	UoL126	UoL127	UoL128	UoL129	UoL130	UoL131	UoL132	UoL133	UoL134	UoL135	UoL136	UoL137	UoL138	UoL139	UoL140	UoL141	UoL142	UoL143	UoL144	UoL145	UoL146	UoL147	UoL148	UoL149	UoL150	UoL151	UoL152	UoL153	UoL154	UoL155	UoL156	UoL157	UoL158	UoL159	UoL160	UoL161	UoL162	UoL163	UoL164	UoL165	UoL166	UoL167	UoL168	UoL169	UoL170	UoL171	UoL172	UoL173	UoL174	UoL175	UoL176	UoL177	UoL178	UoL179	UoL180	UoL181	UoL182	UoL183	UoL184	UoL185	UoL186	UoL187	UoL188	UoL189	UoL190	UoL191	UoL192	UoL193	UoL194	UoL195	UoL196	UoL197	UoL198	UoL199	UoL200	UoL201	UoL202	UoL203	UoL204	UoL205	UoL206	UoL207	UoL208	UoL209	UoL210	UoL211	UoL212	UoL213	UoL214	UoL215	UoL216	UoL217	UoL218	UoL219	UoL220	UoL221	UoL222	UoL223	UoL224	UoL225	UoL226	UoL227	UoL228	UoL229	UoL230	UoL231	UoL232	UoL233	UoL234	UoL235	UoL236	UoL237	UoL238	UoL239	UoL240	UoL241	UoL242	UoL243	UoL244	UoL245	UoL246	UoL247	UoL248	UoL249	UoL250	UoL251	UoL252	UoL253	UoL254	UoL255	UoL256	UoL257	UoL258	UoL259	UoL260	UoL261	UoL262	UoL263	UoL264	UoL265	UoL266	UoL267	UoL268	UoL269	UoL270	UoL271	UoL272	UoL273	UoL274	UoL275	UoL276	UoL277	UoL278	UoL279	UoL280	UoL281	UoL282	UoL283	UoL284	UoL285	UoL286	UoL287	UoL288	UoL289	UoL290	UoL291	UoL292	UoL293	UoL294	UoL295	UoL296	UoL297	UoL298	UoL299	UoL300	UoL301	UoL302	UoL303	UoL304	UoL305	UoL306	UoL307	UoL308	UoL309	UoL310	UoL311	UoL312	UoL313	UoL314	UoL315	UoL316	UoL317	UoL318	UoL319	UoL320	UoL321	UoL322	UoL323	UoL324	UoL325	UoL326	UoL327	UoL328	UoL329	UoL330	UoL331	UoL332	UoL333	UoL334	UoL335	UoL336	UoL337	UoL338	UoL339	UoL340	UoL341	UoL342	UoL343	UoL344	UoL345	UoL346	UoL347	UoL348	UoL349	UoL350	UoL351	UoL352	UoL353	UoL354	UoL355	UoL356	UoL357	UoL358	UoL359	UoL360	UoL361	UoL362	UoL363	UoL364	UoL365	UoL366	UoL367	UoL368	UoL369	UoL370	UoL371	UoL372	UoL373	UoL374	UoL375	UoL376	UoL377	UoL378	UoL379	UoL380	UoL381	UoL382	UoL383	UoL384	UoL385	UoL386	UoL387	UoL388	UoL389	UoL390	UoL391	UoL392	UoL393	UoL394	UoL395	UoL396	UoL397	UoL398	UoL399	UoL400	UoL401	UoL402	UoL403	UoL404	UoL405	UoL406	UoL407	UoL408	UoL409	UoL410	UoL411	UoL412	UoL413	UoL414	UoL415	UoL416	UoL417	UoL418	UoL419	UoL420	UoL421	UoL422	UoL423	UoL424	UoL425	UoL426	UoL427	UoL428	UoL429	UoL430	UoL431	UoL432	UoL433	UoL434	UoL435	UoL436	UoL437	UoL438	UoL439	UoL440	UoL441	UoL442	UoL443	UoL444	UoL445	UoL446	UoL447	UoL448	UoL449	UoL450	UoL451	UoL452	UoL453	UoL454	UoL455	UoL456	UoL457	UoL458	UoL459	UoL460	UoL461	UoL462	UoL463	UoL464	UoL465	UoL466	UoL467	UoL468	UoL469	UoL470	UoL471	UoL472	UoL473	UoL474	UoL475	UoL476	UoL477	UoL478	UoL479	UoL480	UoL481	UoL482	UoL483	UoL484	UoL485	UoL486	UoL487	UoL488	UoL489	UoL490	UoL491	UoL492	UoL493	UoL494	UoL495	UoL496	UoL497	UoL498	UoL499	UoL500	UoL501	UoL502	UoL503	UoL504	UoL505	UoL506	UoL507	UoL508	UoL509	UoL510	UoL511	UoL512	UoL513	UoL514	UoL515	UoL516	UoL517	UoL518	UoL519	UoL520	UoL521	UoL522	UoL523	UoL524	UoL525	UoL526	UoL527	UoL528	UoL529	UoL530	UoL531	UoL532	UoL533	UoL534	UoL535	UoL536	UoL537	UoL538	UoL539	UoL540	UoL541	UoL542	UoL543	UoL544	UoL545	UoL546	UoL547	UoL548	UoL549	UoL550	UoL551	UoL552	UoL553	UoL554	UoL555	UoL556	UoL557	UoL558	UoL559	UoL560	UoL561	UoL562	UoL563	UoL564	UoL565	UoL566	UoL567	UoL568	UoL569	UoL570	UoL571	UoL572	UoL573	UoL574	UoL575	UoL576	UoL577	UoL578	UoL579	UoL580	UoL581	UoL582	UoL583	UoL584	UoL585	UoL586	UoL587	UoL588	UoL589	UoL590	UoL591	UoL592	UoL593	UoL594	UoL595	UoL596	UoL597	UoL598	UoL599	UoL600	UoL601	UoL602	UoL603	UoL604	UoL605	UoL606	UoL607	UoL608	UoL609	UoL610	UoL611	UoL612	UoL613	UoL614	UoL615	UoL616	UoL617	UoL618	UoL619	UoL620	UoL621	UoL622	UoL623	UoL624	UoL625	UoL626	UoL627	UoL628	UoL629	UoL630	UoL631	UoL632	UoL633	UoL634	UoL635	UoL636	UoL637	UoL638	UoL639	UoL640	UoL641	UoL642	UoL643	UoL644	UoL645	UoL646	UoL647	UoL648	UoL649	UoL650	UoL651	UoL652	UoL653	UoL654	UoL655	UoL656	UoL657	UoL658	UoL659	UoL660	UoL661	UoL662	UoL663	UoL664	UoL665	UoL666	UoL667	UoL668	UoL669	UoL670	UoL671	UoL672	UoL673	UoL674	UoL675	UoL676	UoL677	UoL678	UoL679	UoL680	UoL681	UoL682	UoL683	UoL684	UoL685	UoL686	UoL687	UoL688	UoL689	UoL690	UoL691	UoL692	UoL693	UoL694	UoL695	UoL696	UoL697	UoL698	UoL699	UoL700	UoL701	UoL702	UoL703	UoL704	UoL705	UoL706	UoL707	UoL708	UoL709	UoL710	UoL711	UoL712	UoL713	UoL714	UoL715	UoL716	UoL717	UoL718	UoL719	UoL720	UoL721	UoL722	UoL723	UoL724	UoL725	UoL726	UoL727	UoL728	UoL729	UoL730	UoL731	UoL732	UoL733	UoL734	UoL735	UoL736	UoL737	UoL738	UoL739	UoL740	UoL741	UoL742	UoL743	UoL744	UoL745	UoL746	UoL747	UoL748	UoL749	UoL750	UoL751	UoL752	UoL753	UoL754	UoL755	UoL756	UoL757	UoL758	UoL759	UoL760	UoL761	UoL762	UoL763	UoL764	UoL765	UoL766	UoL767	UoL768	UoL769	UoL770	UoL771	UoL772	UoL773	UoL774	UoL775	UoL776	UoL777	UoL778	UoL779	UoL780	UoL781	UoL782	UoL783	UoL784	UoL785	UoL786	UoL787	UoL788	UoL789	UoL790	UoL791	UoL792	UoL793	UoL794	UoL795	UoL796	UoL797	UoL798	UoL799	UoL800	UoL801	UoL802	UoL803	UoL804	UoL805	UoL806	UoL807	UoL808	UoL809	UoL810	UoL811	UoL812	UoL813	UoL814	UoL815	UoL816	UoL817	UoL818	UoL819	UoL820	UoL821	UoL822	UoL823	UoL824	UoL825	UoL826	UoL827	UoL828	UoL829	UoL830	UoL831	UoL832	UoL833	UoL834	UoL835	UoL836	UoL837	UoL838	UoL839	UoL840	UoL841	UoL842	UoL843	UoL844	UoL845	UoL846	UoL847	UoL848	UoL849	UoL850	UoL851	UoL852	UoL853	UoL854	UoL855	UoL856	UoL857	UoL858	UoL859	UoL860	UoL861	UoL862	UoL863	UoL864	UoL865	UoL866	UoL867	UoL868	UoL869	UoL870	UoL871	UoL872	UoL873	UoL874	UoL875	UoL876	UoL877	UoL878	UoL879	UoL880	UoL881	UoL882	UoL883	UoL884	UoL885	UoL886	UoL887	UoL888	UoL889	UoL890	UoL891	UoL892	UoL893	UoL894	UoL895	UoL896	UoL897	UoL898	UoL899	UoL900	UoL901	UoL902	UoL903	UoL904	UoL905	UoL906	UoL907	UoL908	UoL909	UoL910	UoL911	UoL912	UoL913	UoL914	UoL915	UoL916	UoL917	UoL918	UoL919	UoL920	UoL921	UoL922	UoL923	UoL924	UoL925	UoL926	UoL927	UoL928	UoL929	UoL930	UoL931	UoL932	UoL933	UoL934	UoL935	UoL936	UoL937	UoL938	UoL939	UoL940	UoL941	UoL942	UoL943	UoL944	UoL945	UoL946	UoL947	UoL948	UoL949	UoL950	UoL951	UoL952	UoL953	UoL954	UoL955	UoL956	UoL957	UoL958	UoL959	UoL960	UoL961	UoL962	UoL963	UoL964	UoL965	UoL966	UoL967	UoL968	UoL969	UoL970	UoL971	UoL972	UoL973	UoL974	UoL975	UoL976	UoL977	UoL978	UoL979	UoL980	UoL981	UoL982	UoL983	UoL984	UoL985	UoL986	UoL987	UoL988	UoL989	UoL990	UoL991	UoL992	UoL993	UoL994	UoL995	UoL996	UoL997	UoL998	UoL999	UoL1000	UoL1001	UoL1002	UoL1003	UoL1004	UoL1005	UoL1006	UoL1007	UoL1008	UoL1009	UoL1010	UoL1011	UoL1012	UoL1013	UoL1014	UoL1015	UoL1016	UoL1017	UoL1018	UoL1019	UoL1020	UoL1021	UoL1022	UoL1023	UoL1024	UoL1025	UoL1026	UoL1027	UoL1028	UoL1029	UoL1030	UoL1031	UoL1032	UoL1033	UoL1034	UoL1035	UoL1036	UoL1037	UoL1038	UoL1039	UoL1040	UoL1041	UoL1042	UoL1043	UoL1044	UoL1045	UoL1046	UoL1047	UoL1048	UoL1049	UoL1050	UoL1051	UoL1052	UoL1053	UoL1054	UoL1055	UoL1056	UoL1057	UoL1058	UoL1059	UoL1060	UoL1061	UoL1062	UoL1063	UoL1064	UoL1065	UoL1066	UoL1067	UoL1068	UoL1069	UoL1070	UoL1071	UoL1072	UoL1073	UoL1074	UoL1075	UoL1076	UoL1077	UoL1078	UoL1079	UoL1080	UoL1081	UoL1082	UoL1083	UoL1084	UoL1085	UoL1086	UoL1087	UoL1088	UoL1089	UoL1090	UoL1091	UoL1092	UoL1093	UoL1094	UoL1095	UoL1096	UoL1097	UoL1098	UoL1099	UoL1100	UoL1101	UoL1102	UoL1103	UoL1104	UoL1105	UoL1106	UoL1107	UoL1108	UoL1109	UoL1110	UoL1111	UoL1112	UoL1113	UoL1114	UoL1115	UoL1116	UoL1117	UoL1118



## BID CONTRACT

Principal Office: 4511 Willow Road, Suite 4, Pleasanton, CA 94588  
Telephone: (925) 660-3900 Fax: (925) 660-3933  
Corporate Office: Glendale, CA  
Principal Offices: Sacramento Orange County Santa Clara San Diego Seattle, WA

JOB #

**QUOTATION TO:**

Mr. Allan Daly  
Brightbox Technologies  
2040 Bancroft Way Suite 302  
Berkeley, CA 94704

**JOB NAME/ADDRESS:**

NSAM Monterey  
Glasgow Hall

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**THE CONDITIONS PRINTED EITHER ON THE REVERSE SIDE OR ATTACHED ARE PART HEREOF.**

This work or price quotation does not include detection, abatement, encapsulation or removal of asbestos or products, materials, or equipment containing asbestos.

**SCOPE OF WORK:**

Please accept the following proposal to provide labor, material, equipment and engineering required, as outlined below, for the installation of DDC Controls at Glasgow Hall in Monterey. Controls will be installed as follows:

- Item-1: Provide Project Management labor to attend meetings, manage project schedule, manage project safety requirements, and manage overall project execution.
- Item-2: Provide Engineering labor to develop and generate construction drawings and as-builts.
- Item-3: Provide and install the following equipment:
  - Three (3) Veris Modbus Power Meters, One (1) for each Chiller
  - Three (3) Chiller Evaporator DP Sensors, One (1) for each Chiller
  - Two (2) Veris Modbus Power Meters, One (1) for each Chilled Water Pump
  - Two (2) Chilled Water Pump DP Sensors, One (1) for each Pump
- Item-4: Provide and Install ALC Control Panels as required to support new monitoring points.
- Item-5: Provide 120VAC electrical work as required.
- Item-6: Provide piping work and pipe insulation work as required.
- Item-7: Provide programming, graphics and DDC system start-up.
- Item-8: Provide Three (3) hours of system Training.
- Item-9: Provide One (1) Laptop and One (1) Tablet.

**Proposal Clarifications and Exclusions:**

- All drawings to be provided in Adobe Acrobat PDF format.
- All work to be performed during normal working hours, swing shift and overtime are not included.
- All wire to be exposed plenum rated cable in the ceiling and walls. Conduit is included in Mechanical Rooms and on the roof.
- Repairs to existing systems are not included.

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\*Contractors are required by law to be licensed and regulated by the Contractors' State License Board which has jurisdiction to investigate complaints against contractors if a complaint is filed within three years of the date of the alleged violation. Any questions concerning a contractor may be referred to the Registrar, Contractors' State License Board, P. O. Box 26000, Sacramento, CA 95826.\*

**California State License No. 800423**

The total price of this work is **\$47,508.00**, including all taxes. Terms of payment, unless modified above, are: **0** down payment and the balance due upon the receipt of invoice.

Your signed acceptance of this Bid Contract within 30 days from February 23, 2015 shall, upon the acceptance of the Seller, constitute a contract to perform the work described above, including all Terms and Conditions contained herein.  
Seller shall be defined to mean SUNBELT CONTROLS or its assigns.  
Buyer shall be defined to mean the Owner, Owners/Agent, Builder, Architect, lessees, or any person acting on behalf of any of the foregoing.

Proposal # Glasgow-1

**SEE TERMS AND CONDITIONS TO BID CONTRACT**

**02-23-15**



## BID CONTRACT

Principal Office: 4511 Willow Road, Suite 4, Pleasanton, CA 94588  
Telephone: (925) 660-3900 Fax: (925) 660-3933  
Corporate Office: Glendale, CA  
Principal Offices: Sacramento Orange County Santa Clara San Diego Seattle, WA

**JOB #**

**QUOTATION TO:**

Mr. Allan Daly  
Brightbox Technologies  
2040 Bancroft Way Suite 302  
Berkeley, CA 94704

**JOB NAME/ADDRESS:**

NSAM Monterey  
Watkins Hall

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**THE CONDITIONS PRINTED EITHER ON THE REVERSE SIDE OR ATTACHED ARE PART HEREOF.**

This work or price quotation does not include detection, abatement, encapsulation or removal of asbestos or products, materials, or equipment containing asbestos.

**SCOPE OF WORK:**

Please accept the following proposal to provide labor, material, equipment and engineering required, as outlined below, for the installation of DDC Controls at Watkins Hall in Monterey. Controls will be installed as follows:

- Item-1: Provide Project Management labor to attend meetings, manage project schedule, manage project safety requirements, and manage overall project execution.
- Item-2: Provide Engineering labor to develop and generate construction drawings and as-builts.
- Item-3: Provide and install the following equipment:
- Three (3) Veris Modbus Power Meters, One (1) for each Chiller
  - One (1) Chiller Evaporator DP Sensor for Chiller #3
  - Three (3) Chilled Water Pump DP Sensors, One (1) for each Pump
  - One (1) FC-2-E Chilled Water DP Sensor
  - Two (2) FC-2-E Chilled Water Temperature Sensors (strap-on sensors)
  - One (1) AH-3-2 Chilled Water DP Sensor
  - Two (2) AH-3-2 Chilled Water Temperature Sensors (strap-on sensors)
  - Two (2) Chilled Water Strap-on Sensors located next to Two (2) Existing Well Sensors for lag comparison. Location to be determined, we suggest B233 Chiller.
- Item-4: Provide and Install ALC Control Panels as required to support new monitoring points.
- Item-5: Provide 120VAC electrical work as required.
- Item-6: Provide piping work and pipe insulation work as required.
- Item-7: Provide programming, graphics and DDC system start-up.
- Item-8: Provide Three (3) hours of system Training.
- Item-9: Provide One (1) Laptop and One (1) Tablet.

**Proposal Clarifications and Exclusions:**

- All drawings to be provided in Adobe Acrobat PDF format.
- All work to be performed during normal working hours, swing shift and overtime are not included.
- All wire to be exposed plenum rated cable in the ceiling and walls. Conduit is included in Mechanical Rooms and on the roof.
- Repairs to existing systems are not included.

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"Contractors are required by law to be licensed and regulated by the Contractors' State License Board which has jurisdiction to investigate complaints against contractors if a complaint is filed within three years of the date of the alleged violation. Any questions concerning a contractor may be referred to the Registrar, Contractors' State License Board, P. O. Box 26000, Sacramento, CA 95826."

**California State License No. 800423**

The total price of this work is **\$54,220.00**, including all taxes. Terms of payment, unless modified above, are: **0** down payment and the balance due upon the receipt of invoice.

Proposal # Watkins-1

**SEE TERMS AND CONDITIONS TO BID CONTRACT**

**02-23-15**